Interactive Visual Analysis with **different levels of complexity**

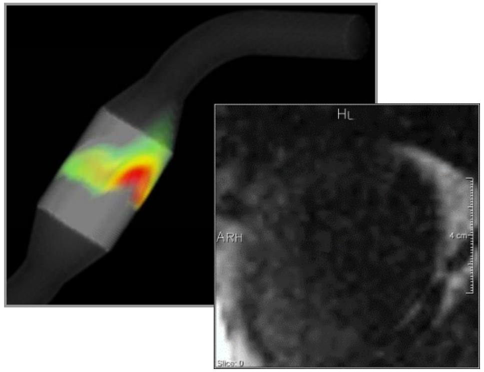
Helwig Hauser,
Delft, 2010-06-24

Introduction

- **Vis**.: good for **exploration/analysis** & **presentation**
  - exploration: visualize to detect the unexpected
  - analysis: check hypotheses with visualization
  - presentation: show / communicate what you've found
- **Focus** here: **interactive visual analysis**, IVA
- **Goal** today: **understanding IVA**
  - levels of IVA
  - patterns of IVA
  - …
- Personal background: ≈10 years of IVA research
  - SimVis, IVA of …, etc., applications, …
  - VisMaster

Basis: Data Model, **domain & range**

- **Data model d(x**, t), independent/dependent variables
- **Domain**: space **x**, time t
  (and …)
  - where? when?
  - 2D/3D space
    1D time
  - parameters
- **Range**: attributes d_i
  - what?
  - several–many d_i
    (can be dozens)
  - often somehow coherent across space-time locations
    (continuous, distributions)
- **Example**:
  - for each of one million grid cells
    at each of hundreds of time steps
  - the simulated values of temperature, pressure, flow velocity, etc., are given



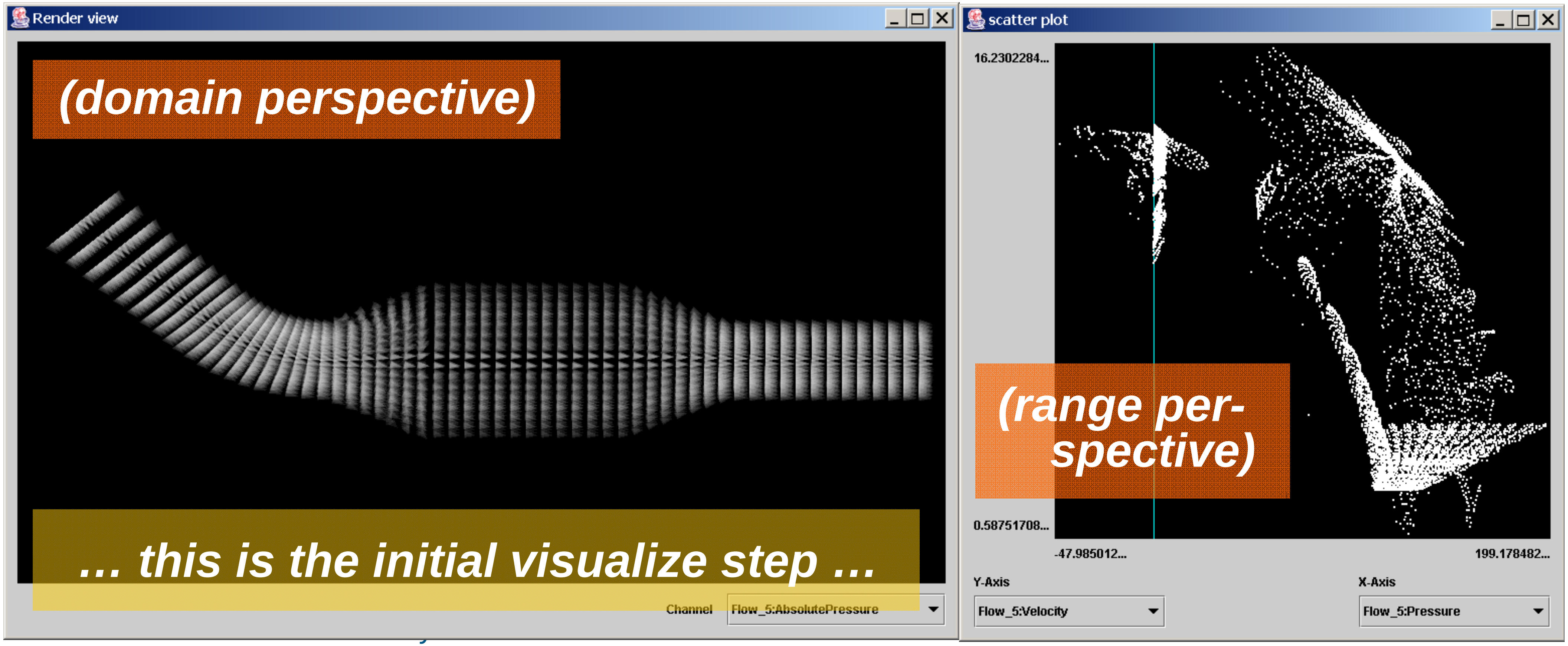
Interactive Visual Data Analysis

- **Main idea**:
  - enabling **interactive** & **iterative** exploration / analysis of complex (multi-variate) and often also large data
  - allowing for **visual information drill-down**, cf. Ben Shneiderman's visual information seeking mantra
  - built around a notion of the **user's interest** – *subjective* & *current* **degree of interest** per data item
- **Different "levels" of IVA**:
  - **show & brush** (tightest IVA loop)
  - **relational analysis** ("reading between the lines")
  - **complex analysis** ("joining forces")
  - and more …

… an example of IVA** (level 1) **first …

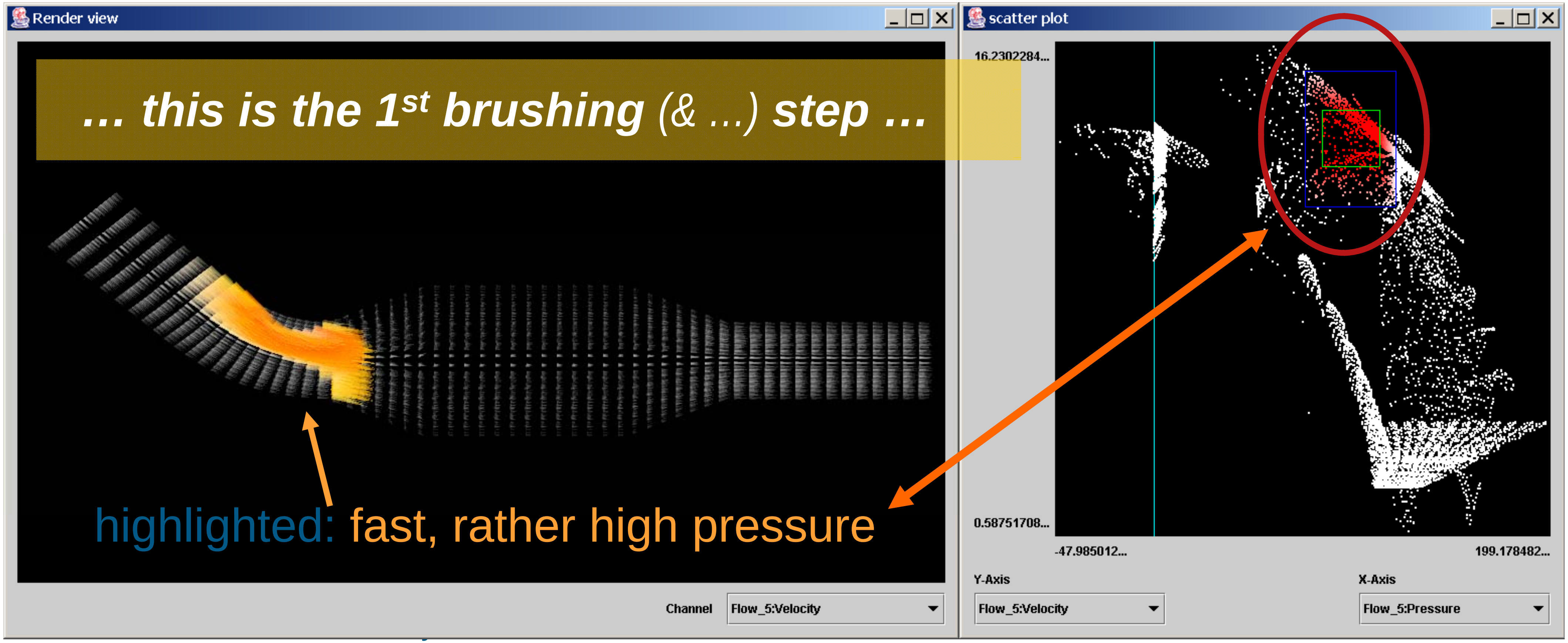
First Example: IVA of Simulation Data

- **Important preliminary**:
  - **multiple views** onto the data (here flow simulation data)
  - often at least one for *domain* variables (here 3D space) and one for *range* variables (here pressure & velocity)



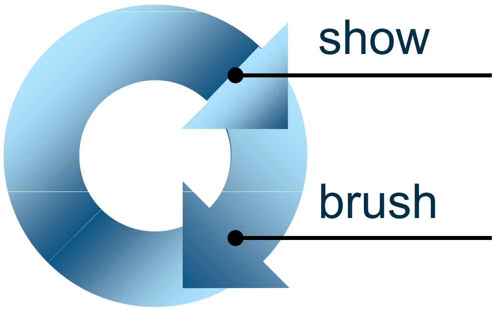
First Example: Linking & Brushing

- **Next: first IVA loop**
  - visualization leads to “I see (something)!” effect
  - user brushes “this something” (literally!)
  - linked visualization reveals insight!



Show & Brush (IVA level 1)

- **Tightest IVA loop**
  - **show data** (explicitly represented information)
  - **one brush** (on one view, can work on >1 dims.)



A typical (start into an) **IVA session** of this kind:

- bring up multiple views
  - at least one for **x**, *t*
  - at least one for d_i
- I see (something)!
- brush this "something"
- linked F+C visualization
- first insight!

Show & Brush (IVA level 1)

- **Tightest IVA loop**
  - **show data** (explicitly represented information)
  - **one brush** (on one view, can work on >1 dims.)
- **Requires**:
  - multiple views (≥2)
  - interactive brushing capabilities on views (brushes should be editable)
  - focus+context visualization
  - linking between views

… leads to…

degree of interest

… requires…

… is realized via …

- Allows for **different IVA patterns** (wrt. domain & range)

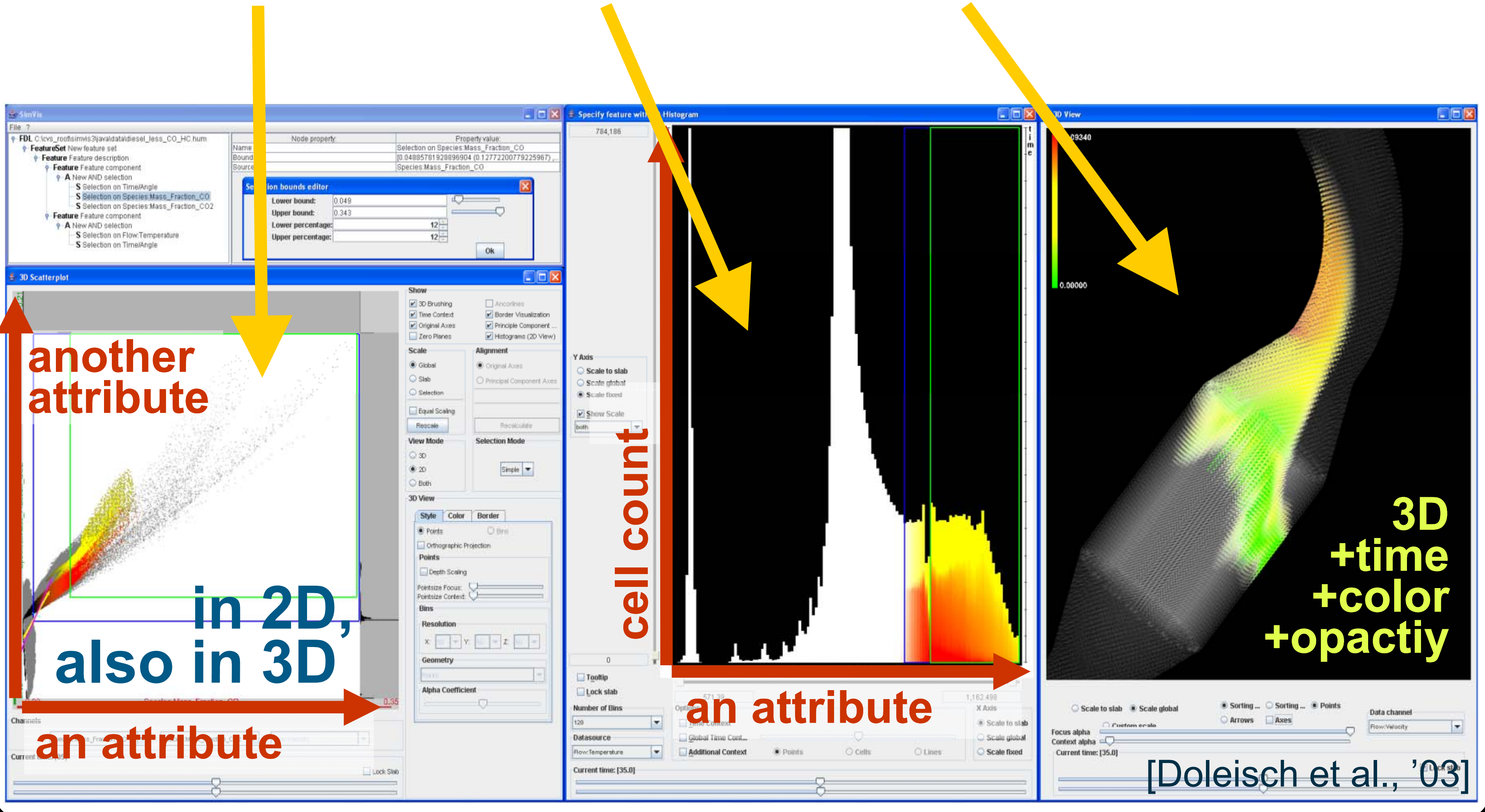
A typical (start into an) **IVA session** of this kind:

- bring up multiple views
  - at least one for **x**, *t*
  - at least one for d_i
- I see (something)!
- brush this “something”
- linked F+C visualization
- first insight!

(next slide)

IVA: Multiple Views

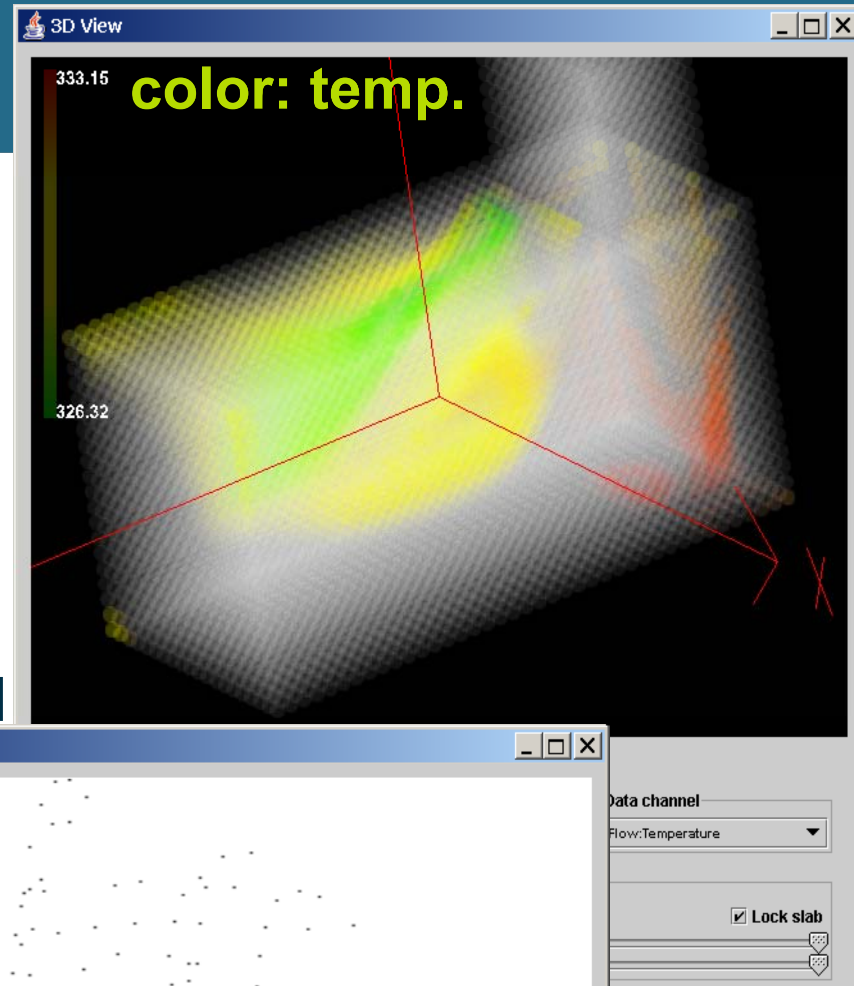
- One dataset, but multiple views
- Scatterplots, histogram, 3D(4D) view, etc.

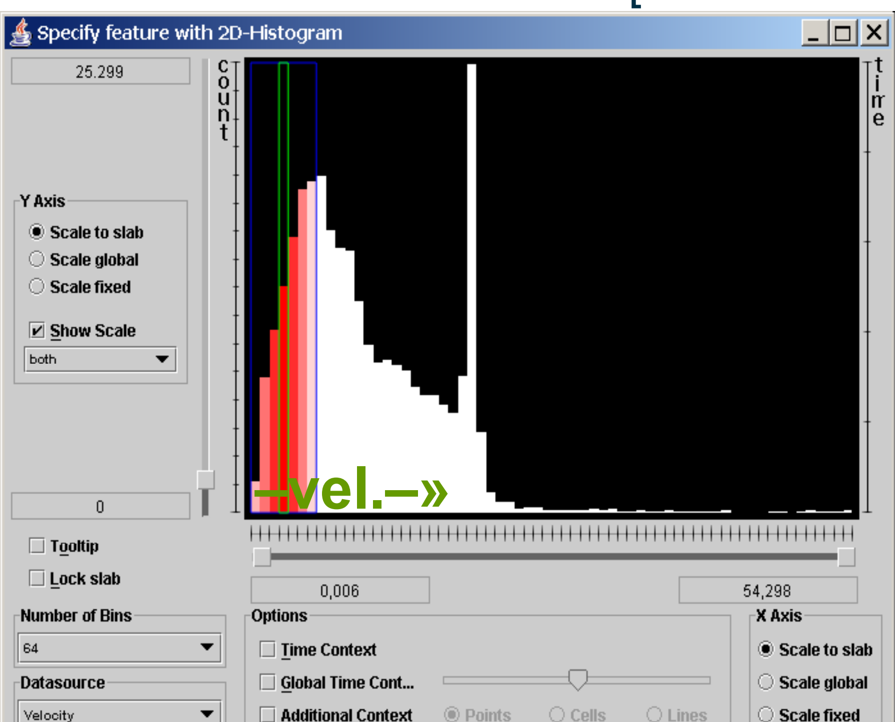


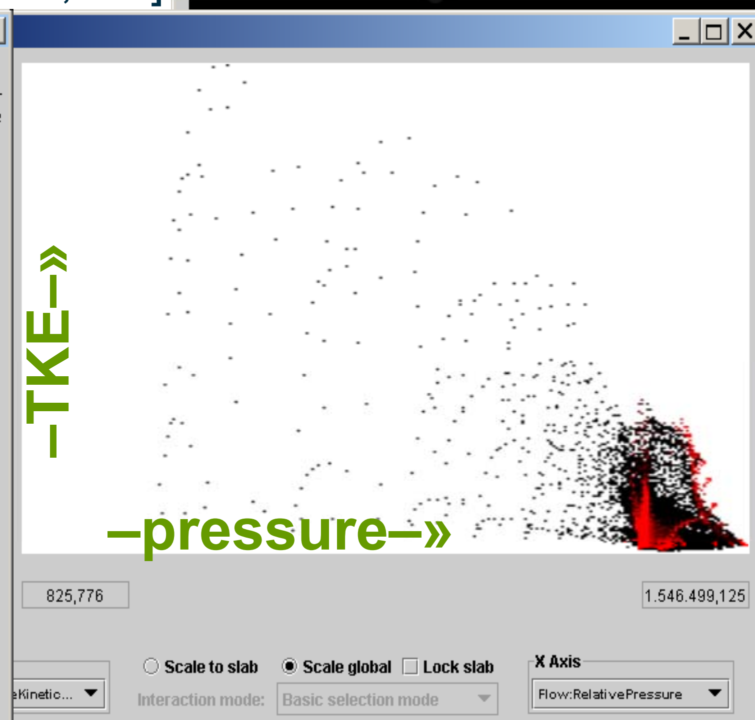
IVA: Interactive Brushing

- Move/alter/extend brush interactively
- Interactively explore/ analyze multiple variates

[Doleisch et al., '03]







(SimVis)

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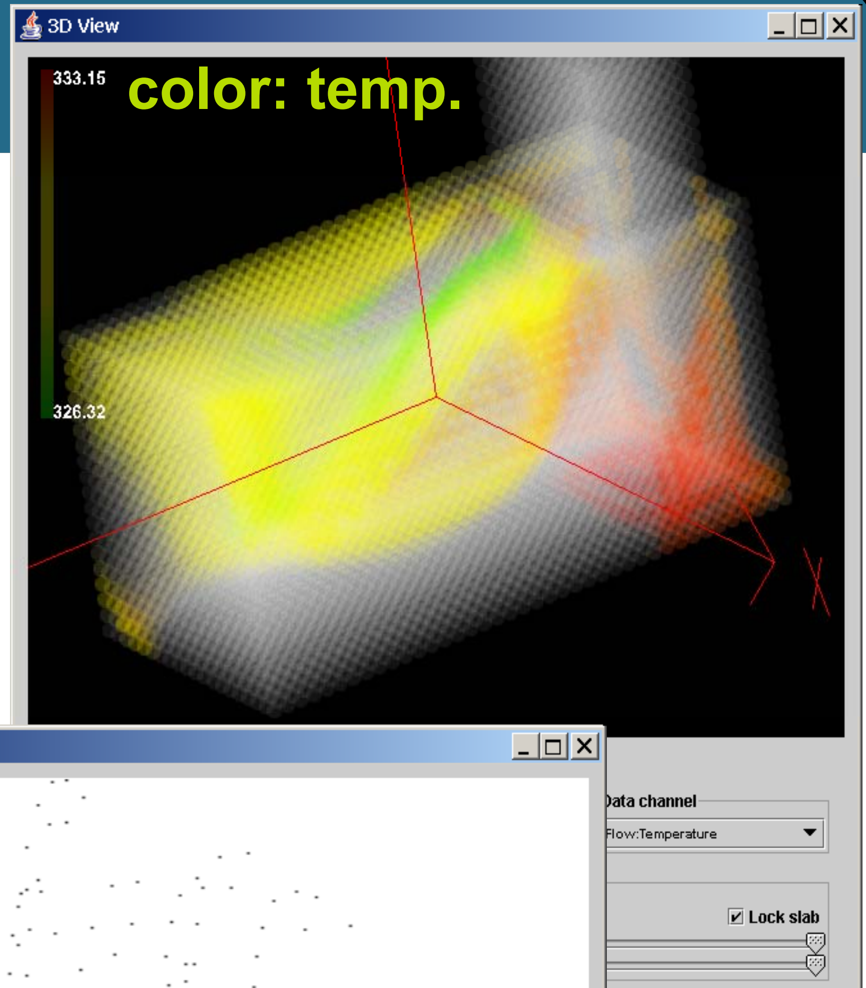

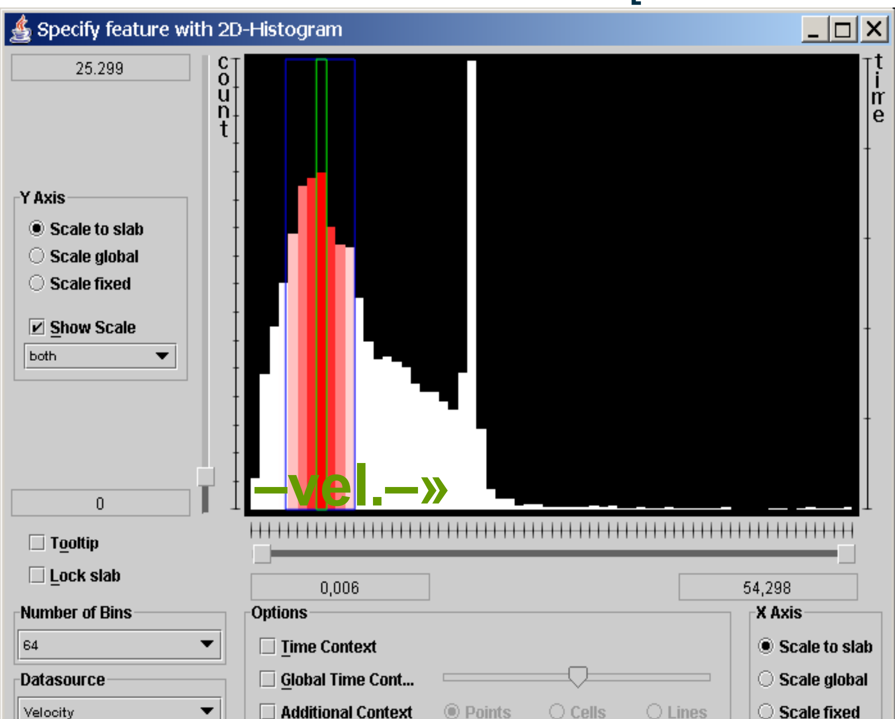

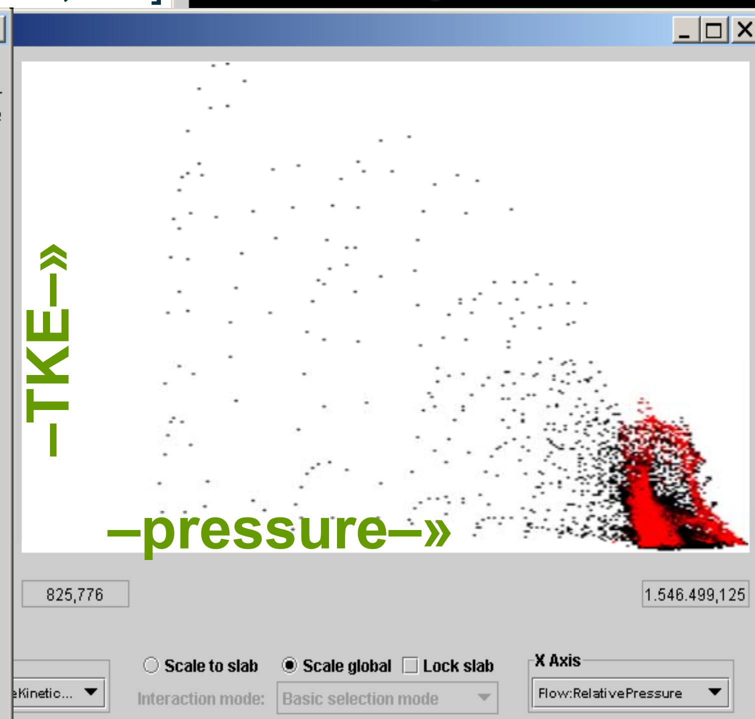

(SimVis)

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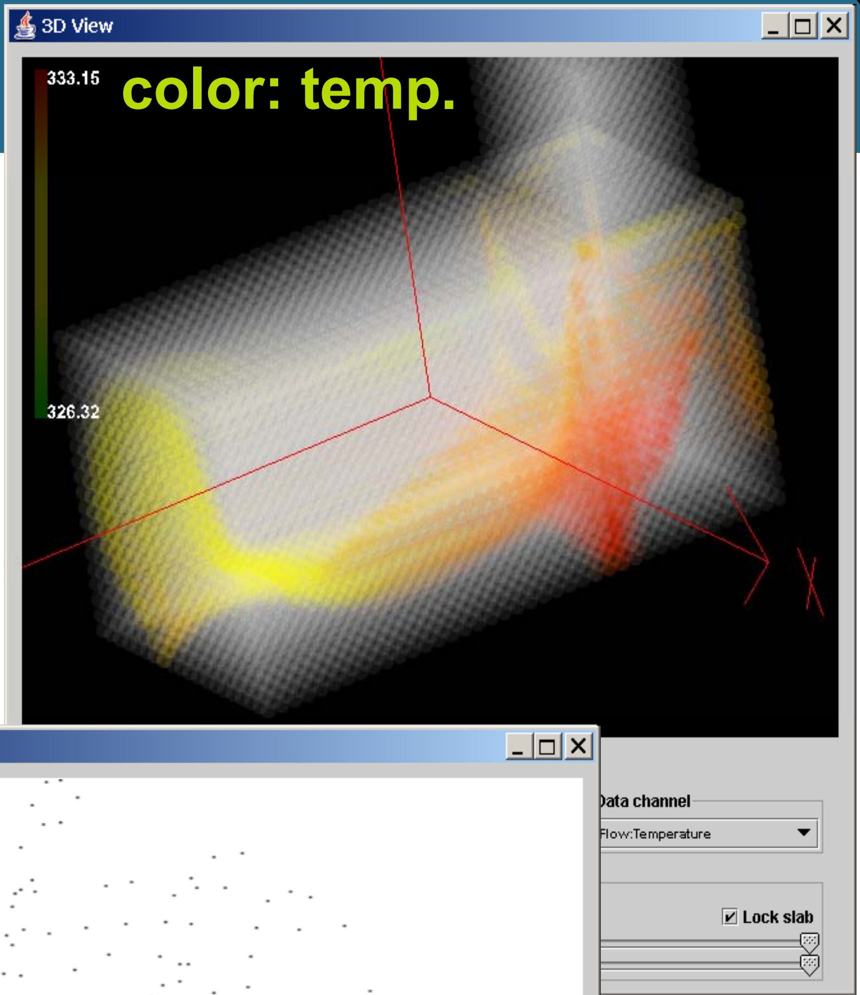

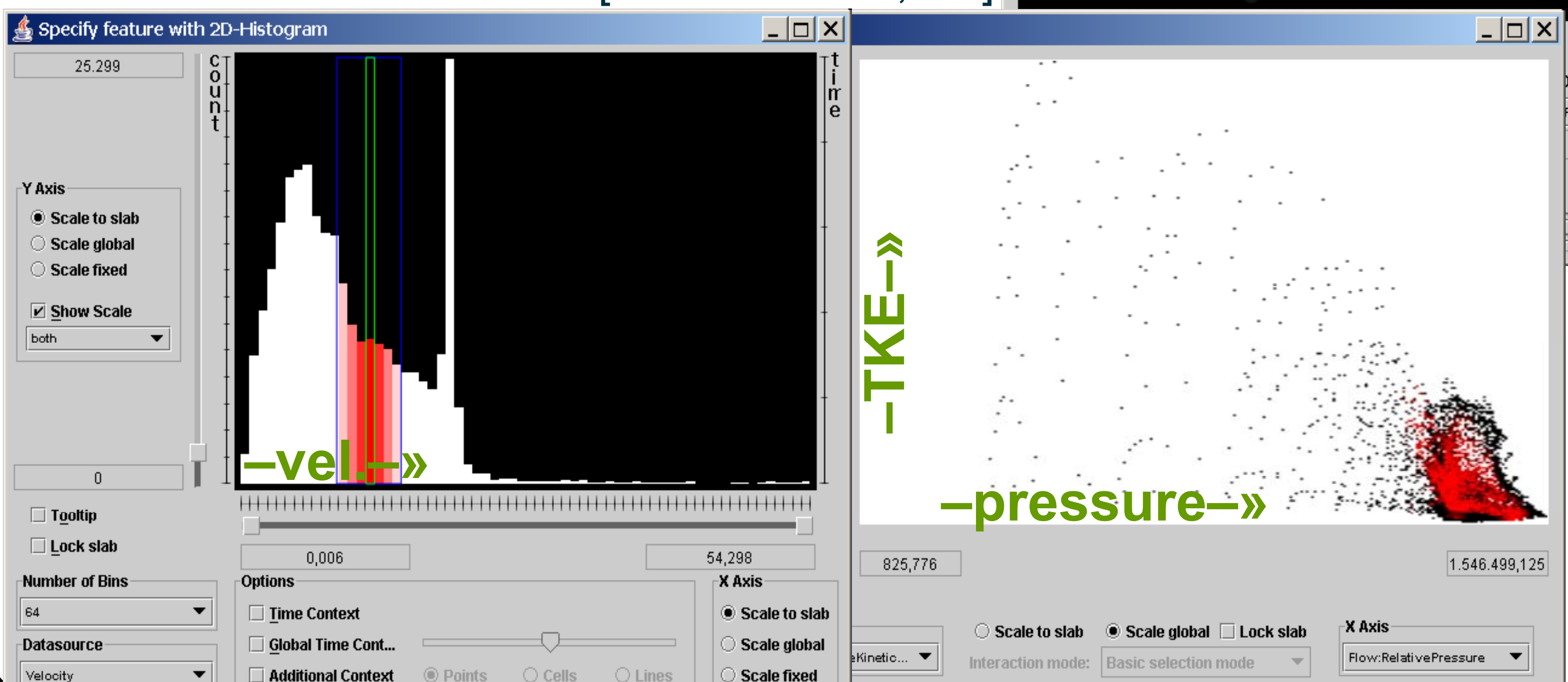

(SimVis)

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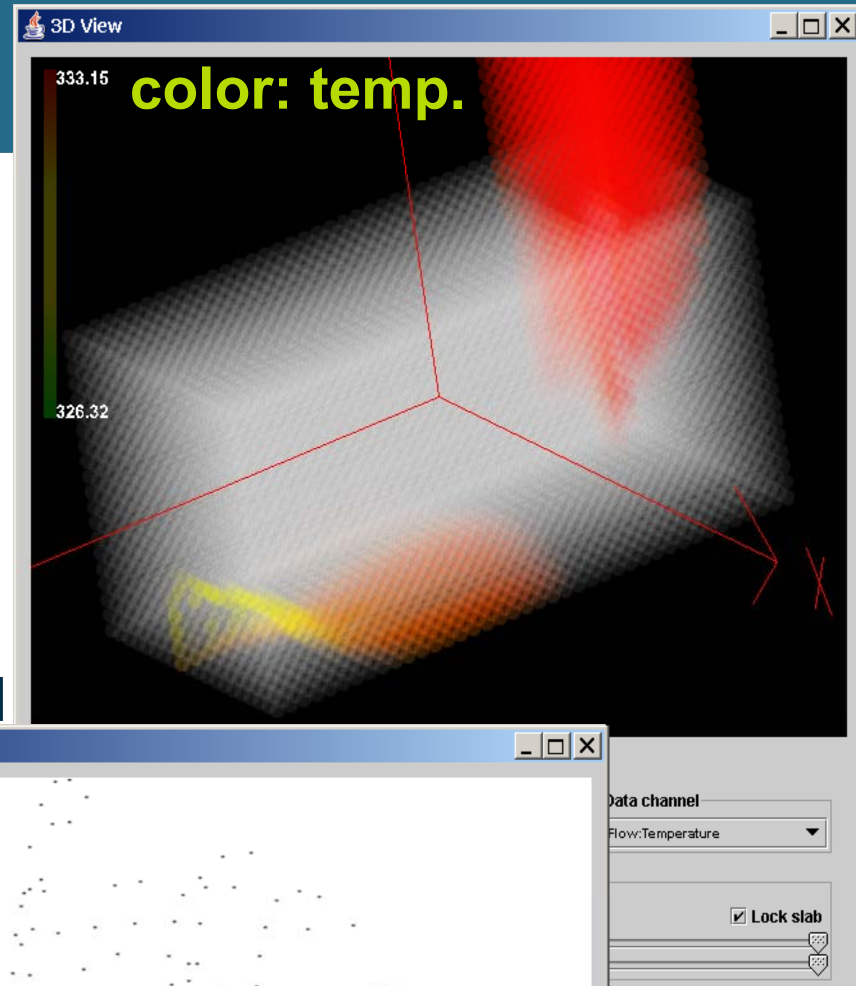

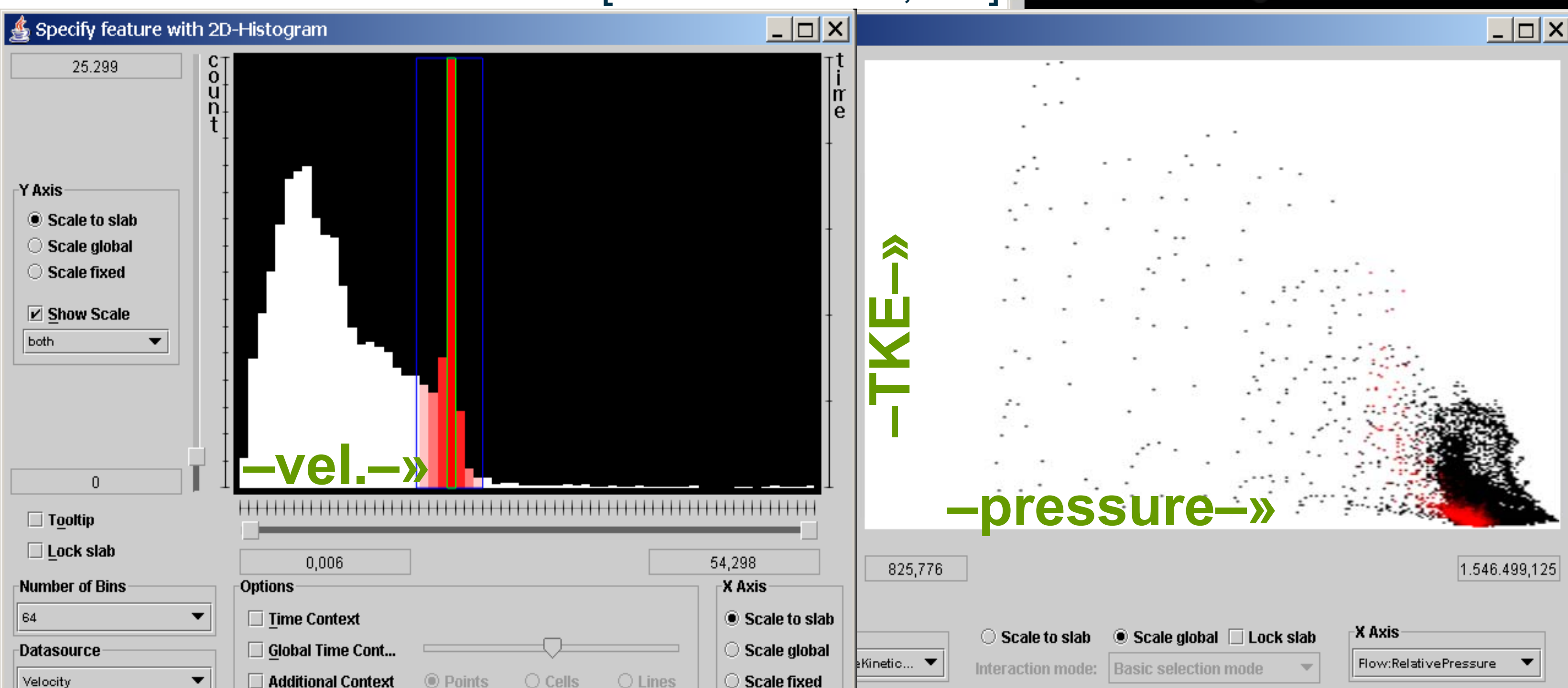

(SimVis)

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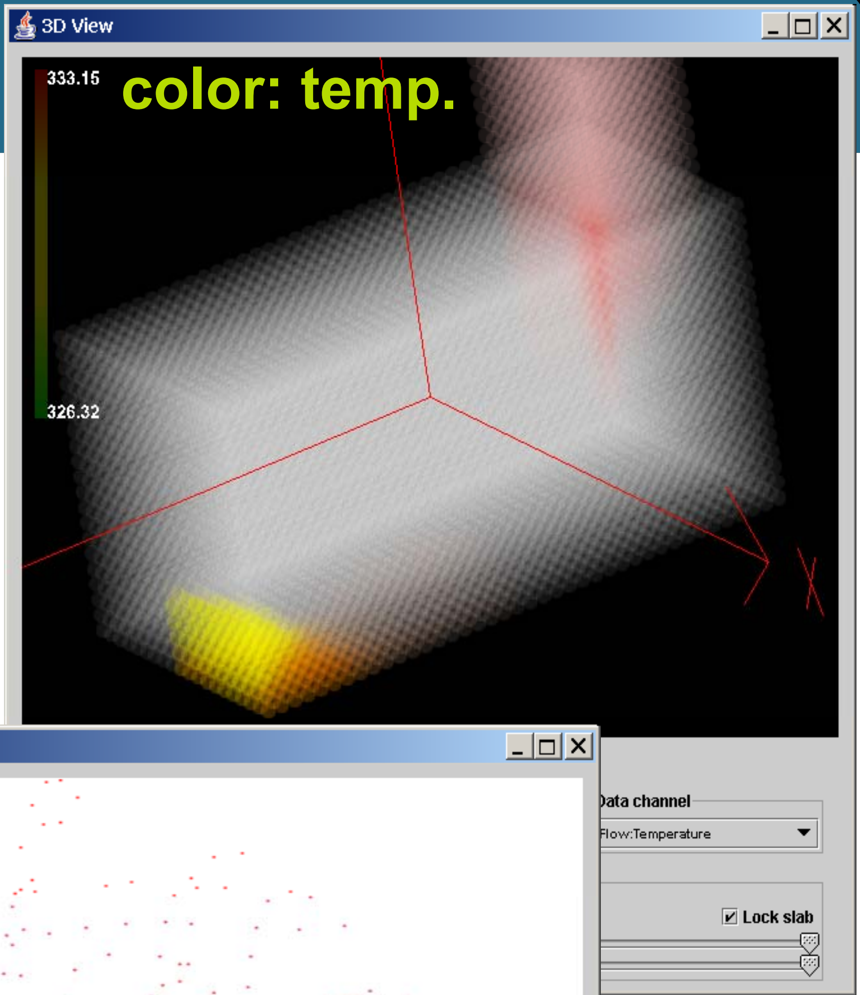
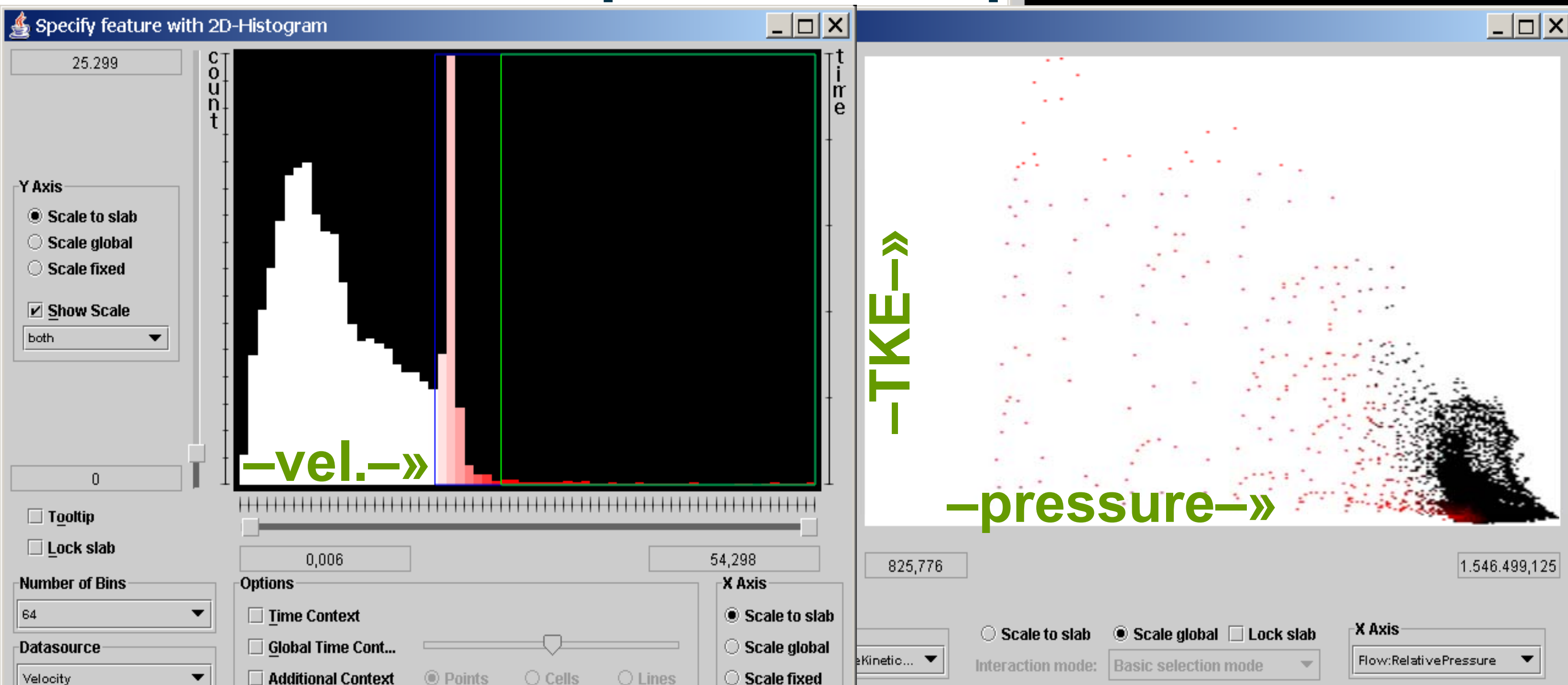


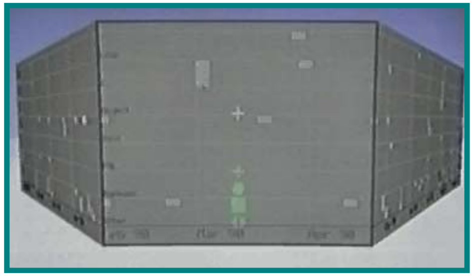


(SimVis)

IVA: Focus+Context Visualization

- Traditionally space distortion
  - more space for data of interest
  - rest as context for orientation

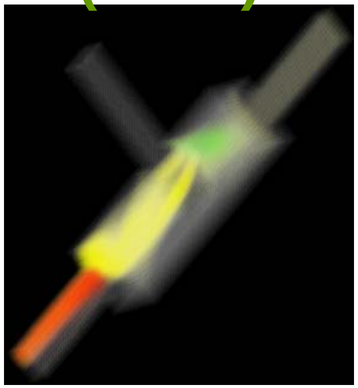
[Mackinlay et al. 1991]



- Generalized F+C visualization
  - emphasize data in focus (color,opacity, …)
  - differentiated use of visualization resources

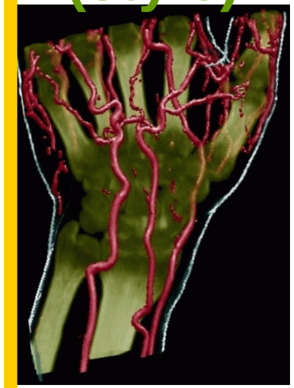
[Hauser… 2001, 2003]

(color)

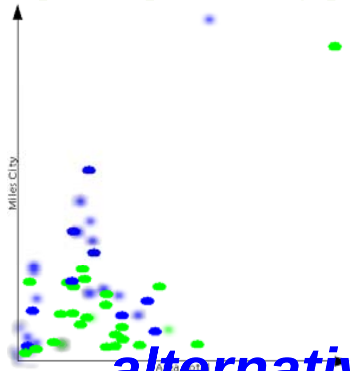


(opacity)

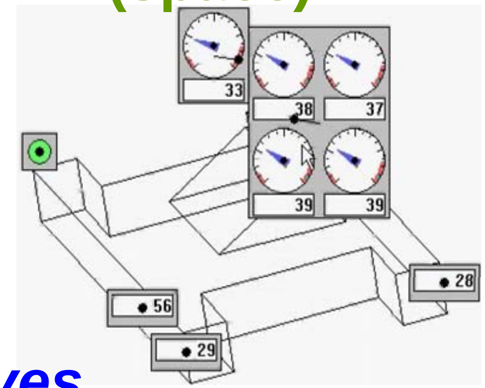
(style)



(frequency)



(space)

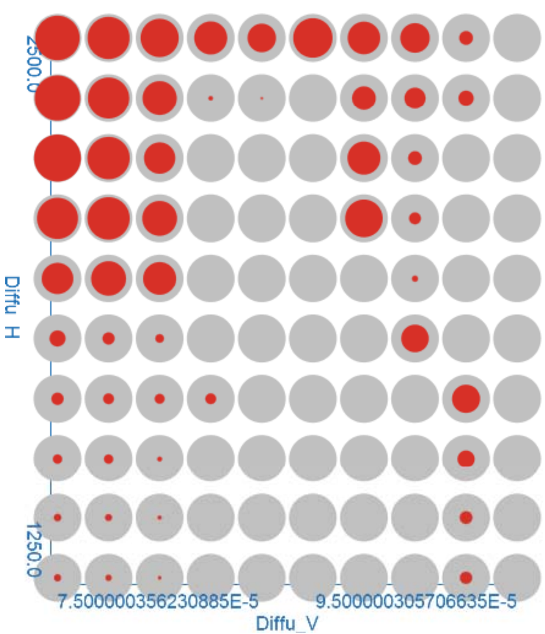


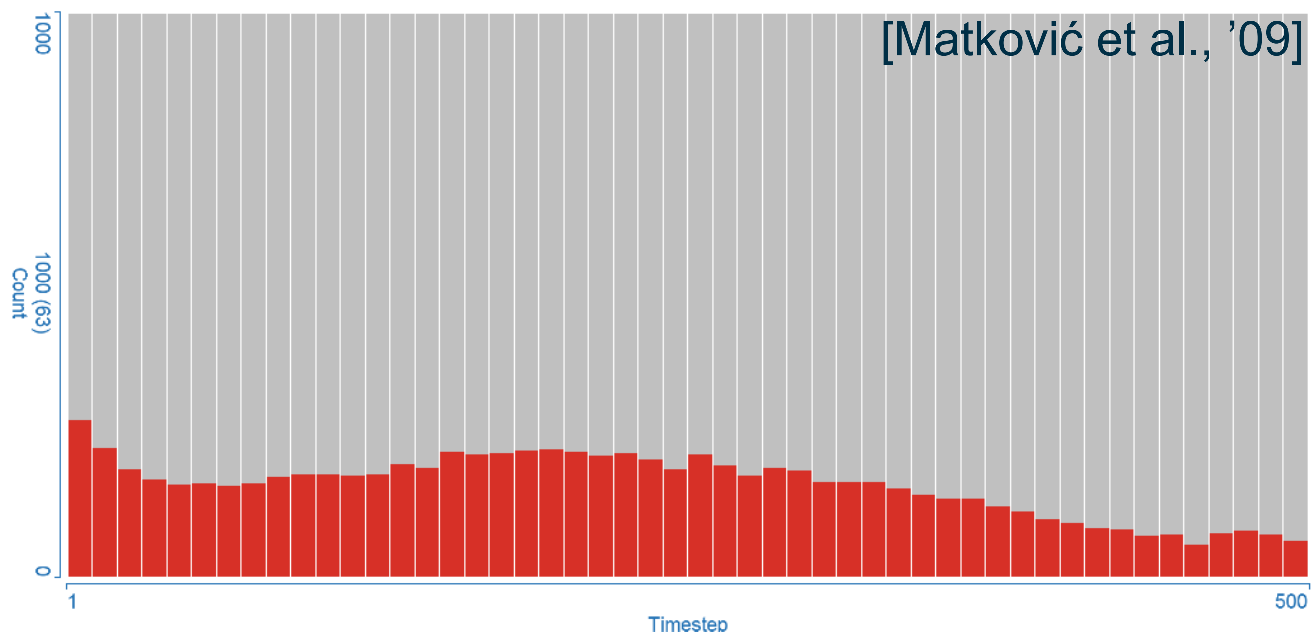
alternatives…

F+C Visualization in IVA Views

- Colored vs. gray-scale visualization
- Opaque vs. semi-transparent visualization

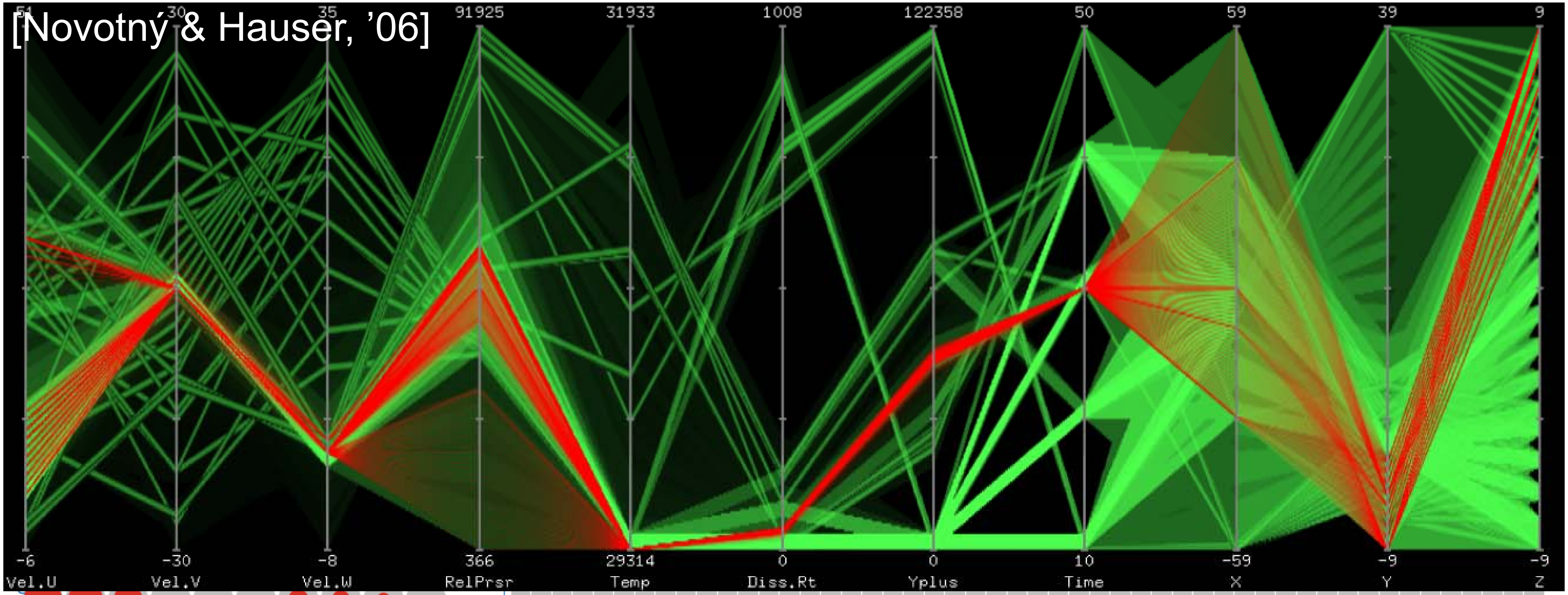
In a scatterplot (left) or histogram (right): brushed data in red…



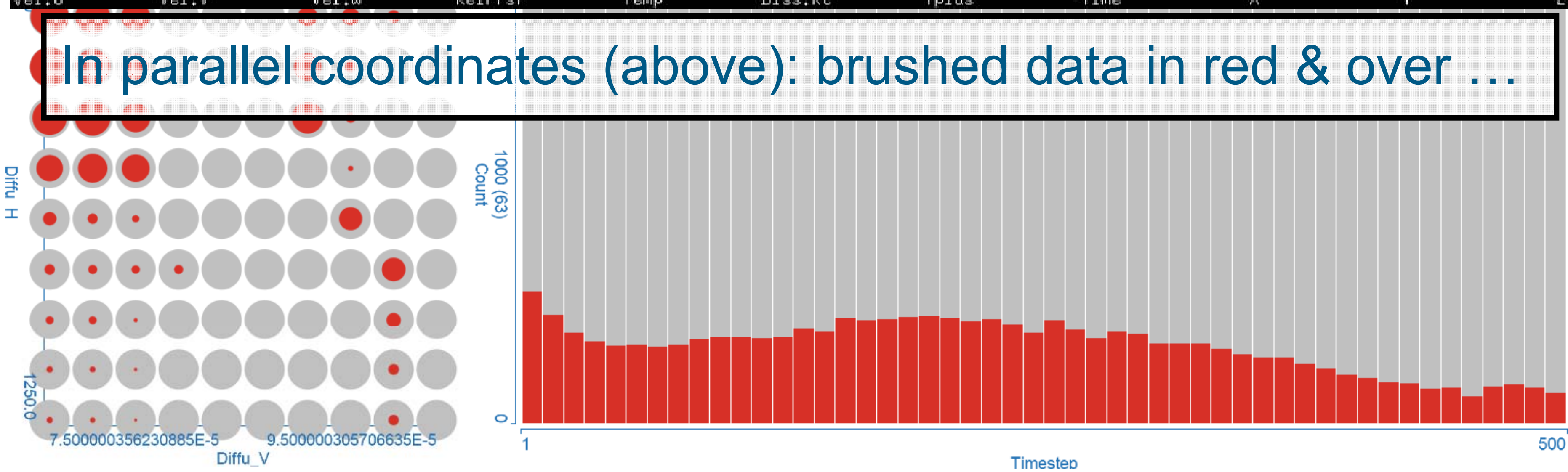


[Matković et al., ’09]

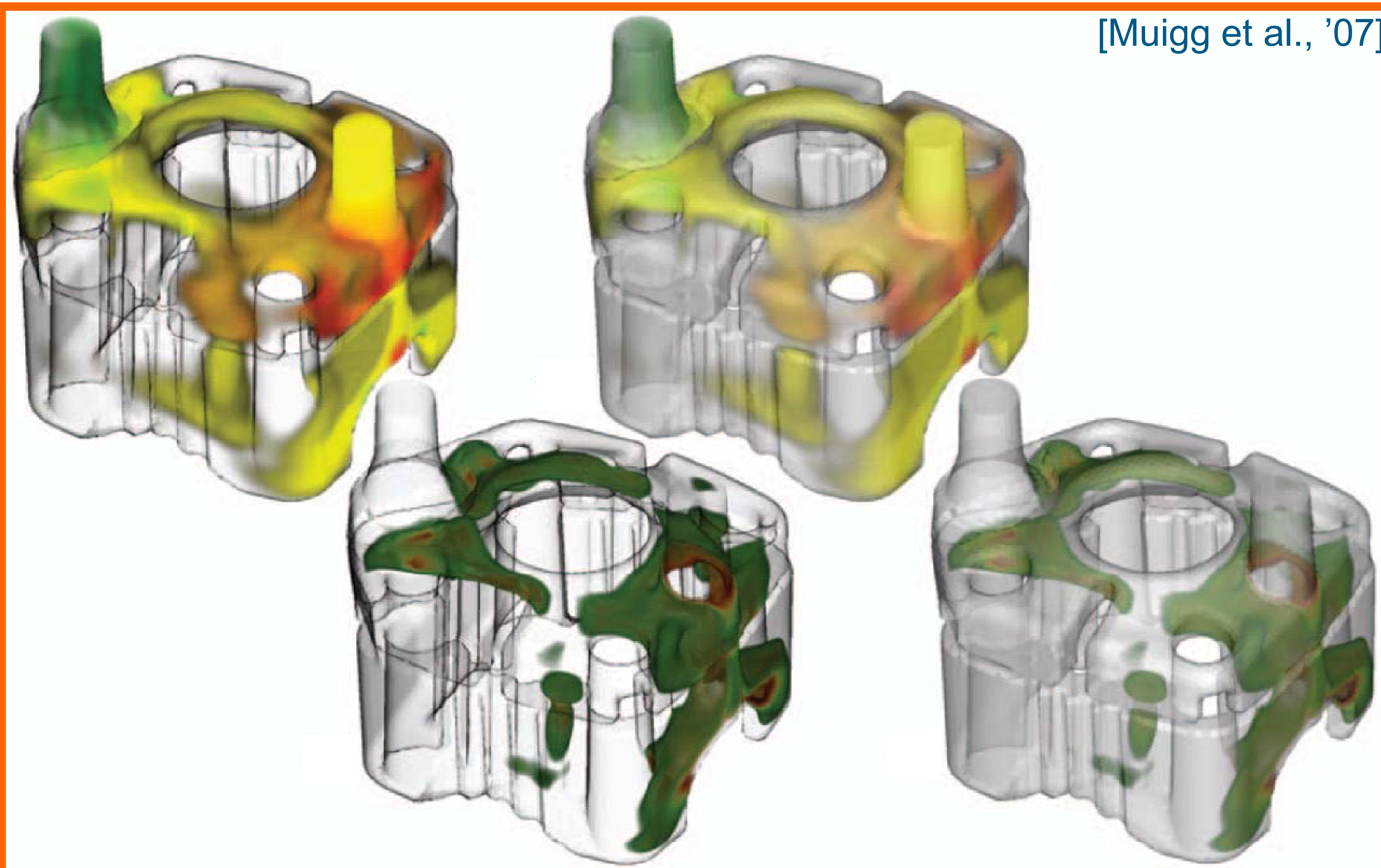
F+C Visualization in IVA Views



In parallel coordinates (above): brushed data in red & over …



F+C Visualization in IVA Views

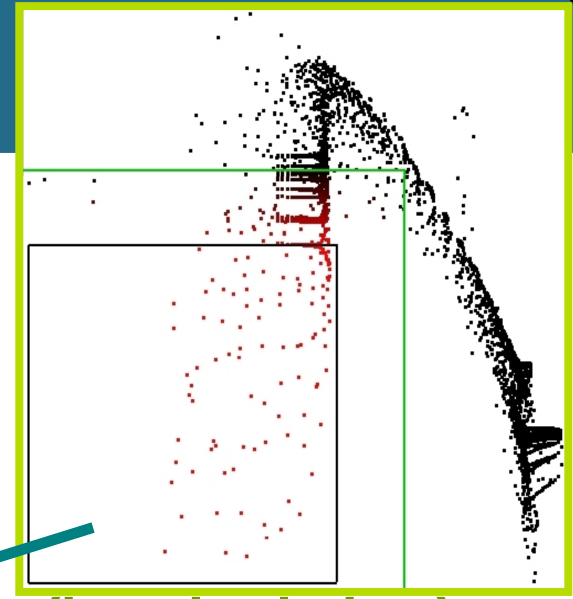


[Muigg et al., '07]

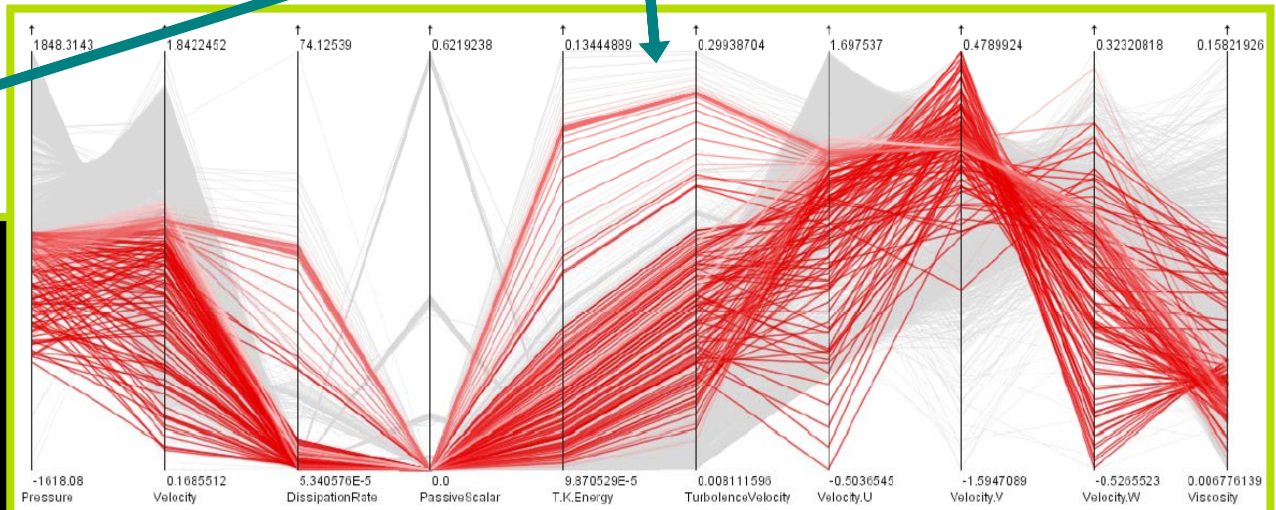
In 3D (above): less transp. & colored, in illustrative context …

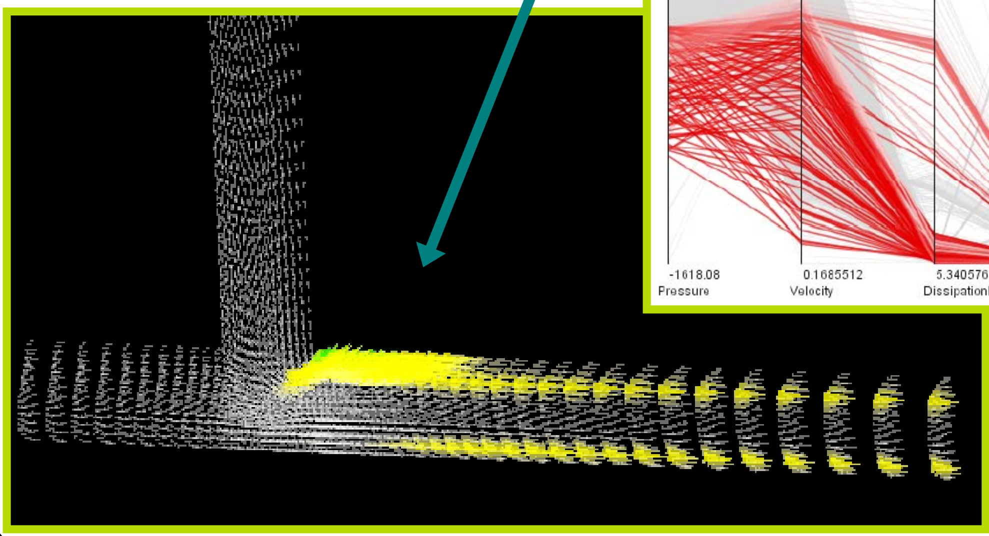
IVA: Linked Views

- Brushing: mark data subset as especially intersting
- Linking: enhance brushed data in linked views consistently (F+C)



(brushed view)



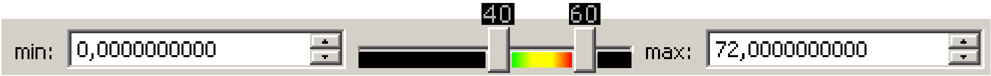


(linked views)

[Doleisch & Hauser, ’02]

IVA: Degree of Interest (DOI)

- *doi*(.): data items tr_i (table rows) → degree of interest *doi*(tr_i) ∈ [0,1]
  - *doi*(tr_i) = 0 ⇒ tr_i not interesting (tr_i ∈ context)
  - *doi*(tr_i) = 1 ⇒ tr_i 100% interesting (tr_i ∈ focus)
- Specification
  - explicit, e.g., through direct selection
  - implicit, e.g., through a range slider



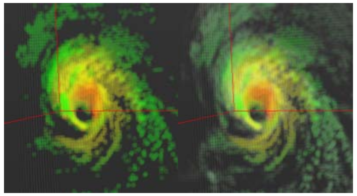
- Fractional DOI values: 0 ≤ *doi*(tr_i) ≤ 1
  - several levels (0, low, med., …)
  - a continuous measure of interest
  - a probabilistic definition of interest

x	*y*	*d1*	*d2*	*doi*
0	0	17,20	-0,22	*0,00*
1	0	12,10	0,10	*0,00*
2	0	7,70	0,45	*0,00*
3	0	2,10	0,90	*0,00*
0	1	24,10	0,02	*0,00*
1	1	21,90	0,36	*0,00*
2	1	15,50	0,87	*0,74*
3	1	11,10	1,20	*1,00*
0	2	27,20	0,12	*0,00*
1	2	24,10	0,66	*0,18*
2	2	17,30	1,35	*1,00*
3	2	12,10	2,20	*0,60*
0	3	35,50	0,67	*0,00*
1	3	30,90	1,30	*0,00*
2	3	24,50	2,10	*0,10*
3	3	20,80	2,90	*0,00*

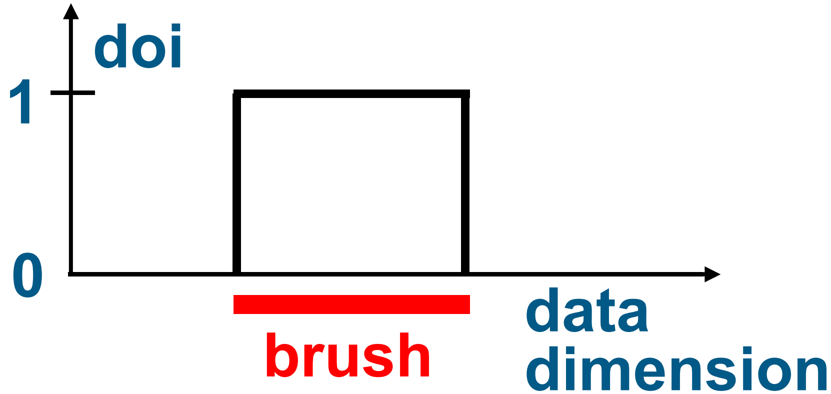
(cont'd on next slide)

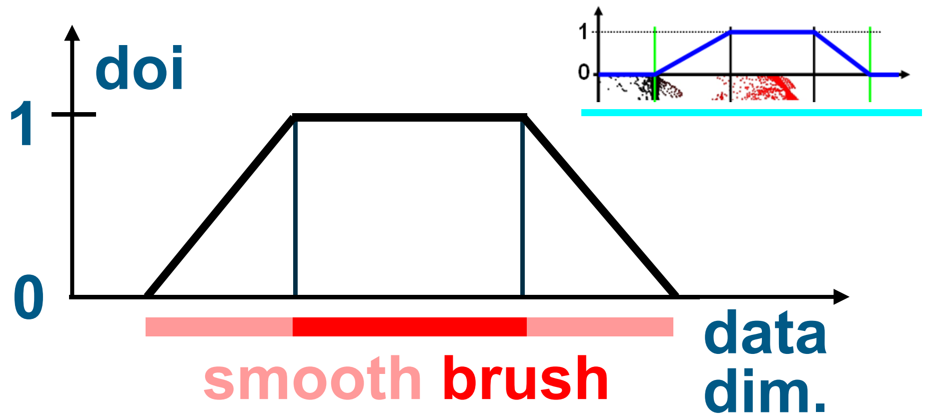
IVA: Smooth Brushing → Fractional DOI

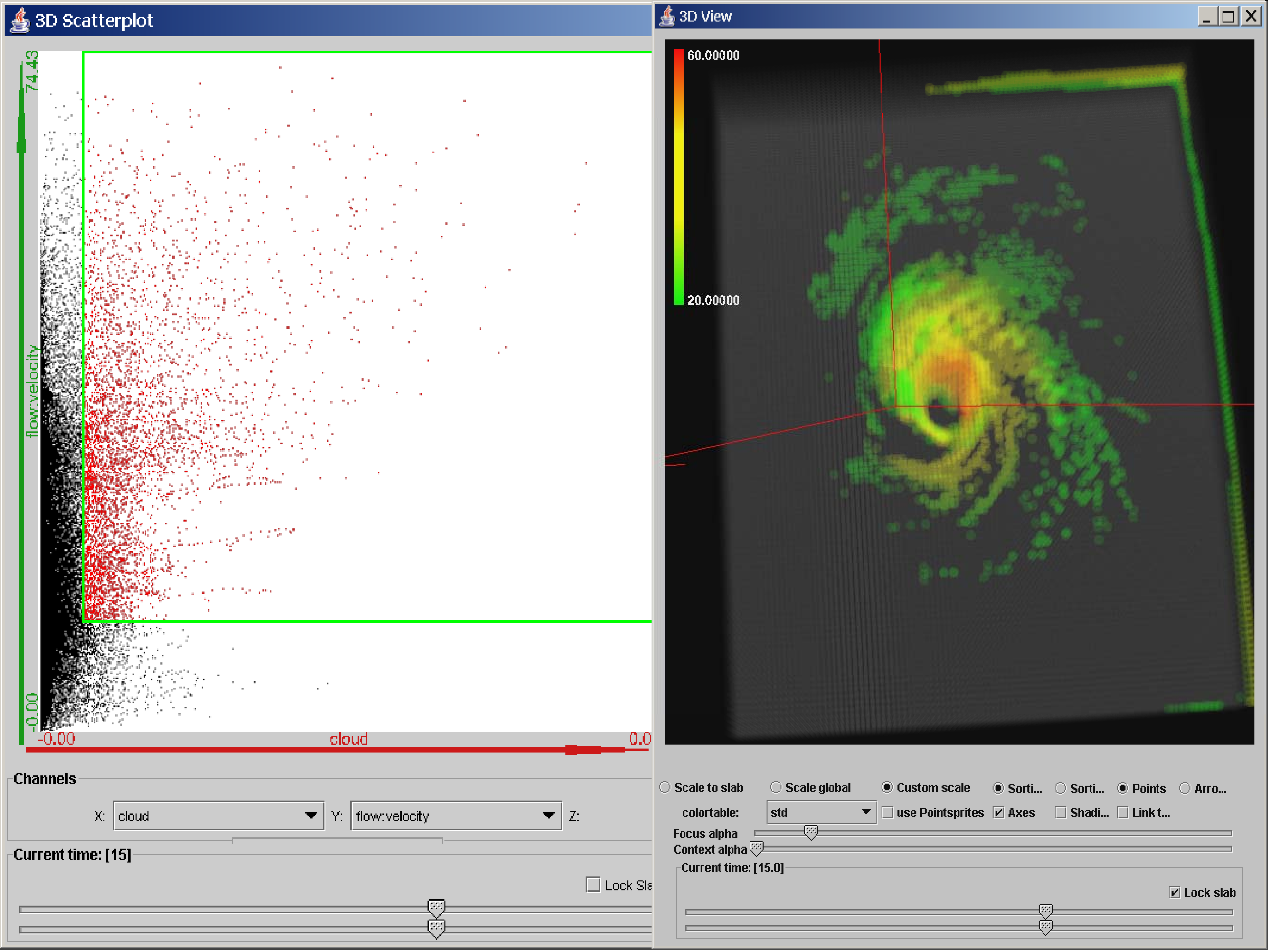
- **Fractional DOI values** esp. useful wrt. **scientific data**: (quasi-)continuous nature of data ↔ smooth borders
- Goes well with gradual focus+context vis. techniques (coloring, semitransparency)



- Specification: **smooth brushing** [Doleisch & Hauser, 2002]
  - “inner” range: all 100% interesting (DOI values of 1)
  - between “inner” & “outer” range: fractional DOI values
  - outside “outer” range: not interesting (DOI values of 0)







3D Scatterplot
74.43
flow:velocity
-0.00
-0.00
cloud
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Channels
X: cloud
Y: flow:velocity
Z:
Current time: [15]
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Current time: [15.0]
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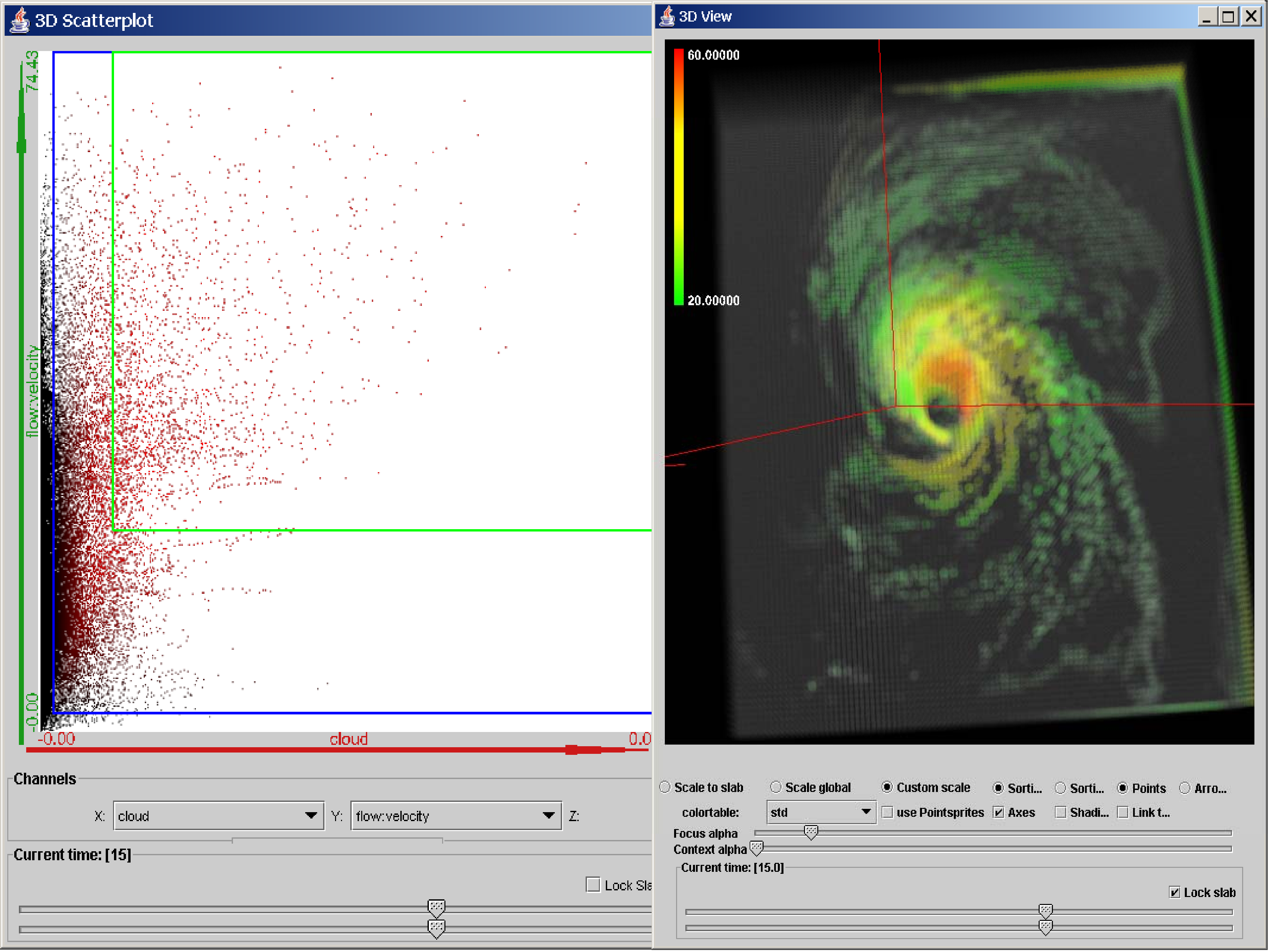
3D Scatterplot
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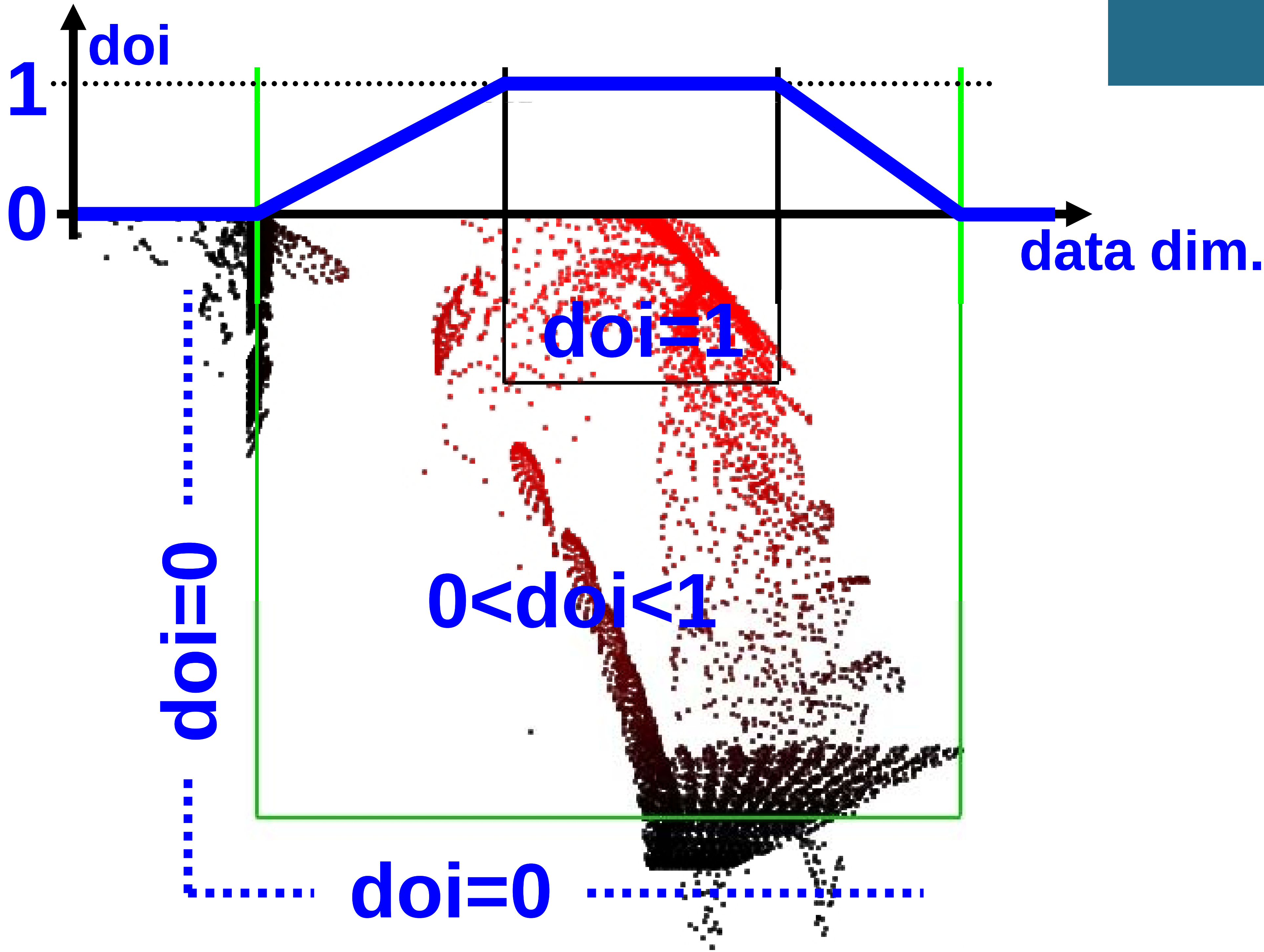

doi
1
0
data dim.
doi=1
0<doi<1
doi=0
doi=0

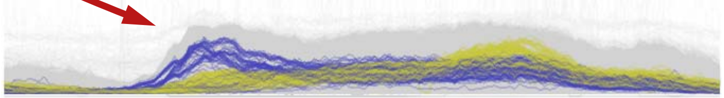
Three Patterns of IVA

[more traffic exploration]

- Preliminary: domain **x** & range **d** visualized (≥2 views)
  - **brushing on domain visualization,** e.g., brushing special locations in the map view

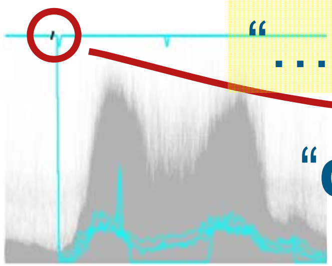
“x”

“… from **x** to **d** …”



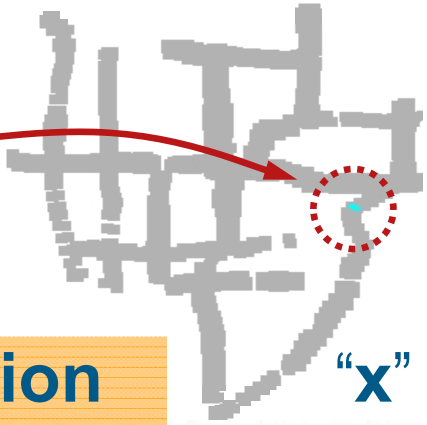
❶ ► **local investigation** “d”

  - **brushing on range visualization,** e.g., brushing outlier curves in a function graph view



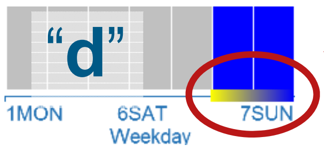
“… from **d** to **x** …”

“d”

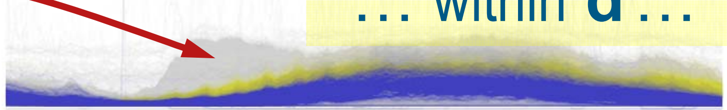


❷ ► **feature localization** “x”

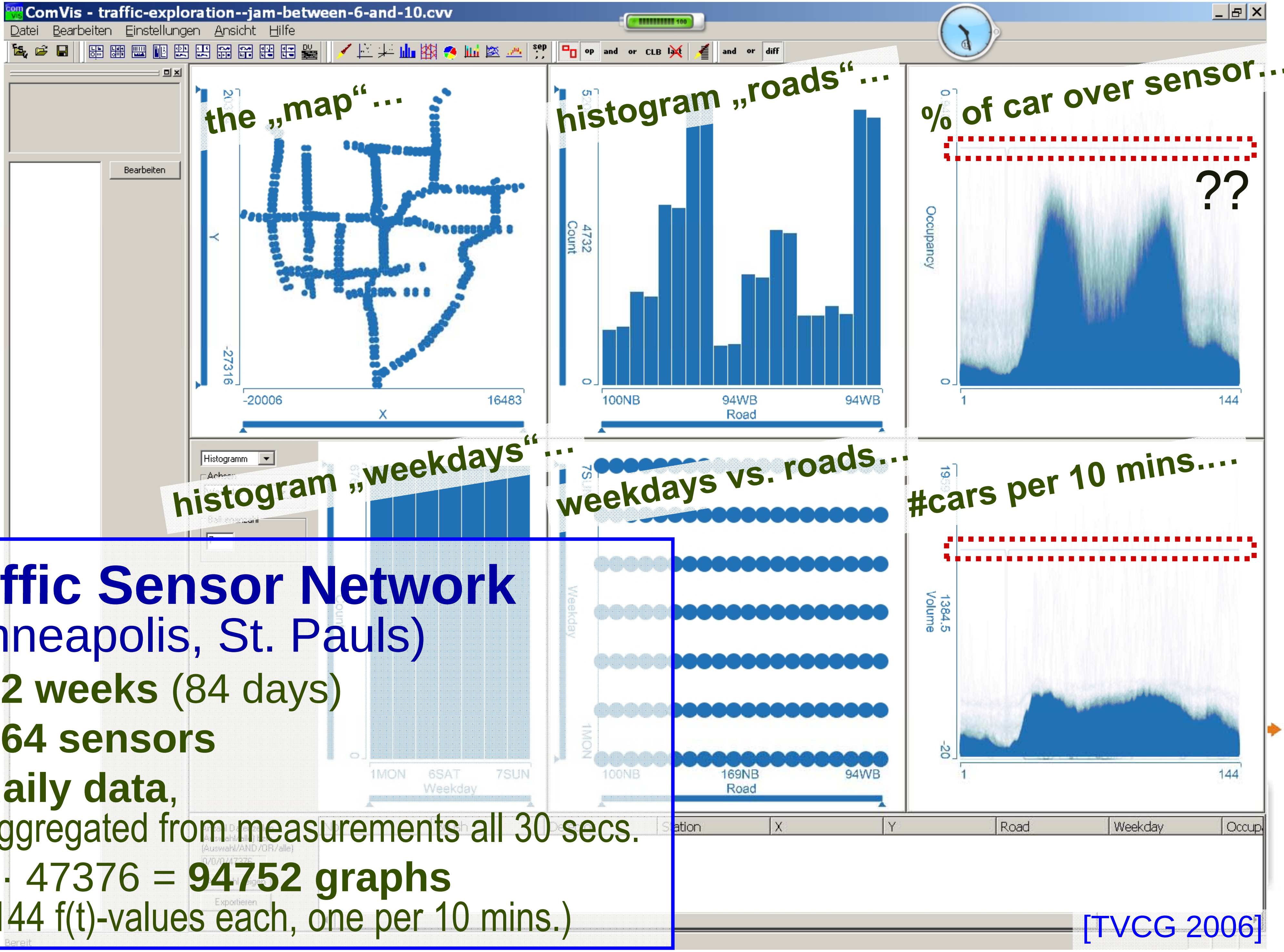
relating multiple range variates



“… within **d** …”



❸ ► **multi-variate analysis** “d”

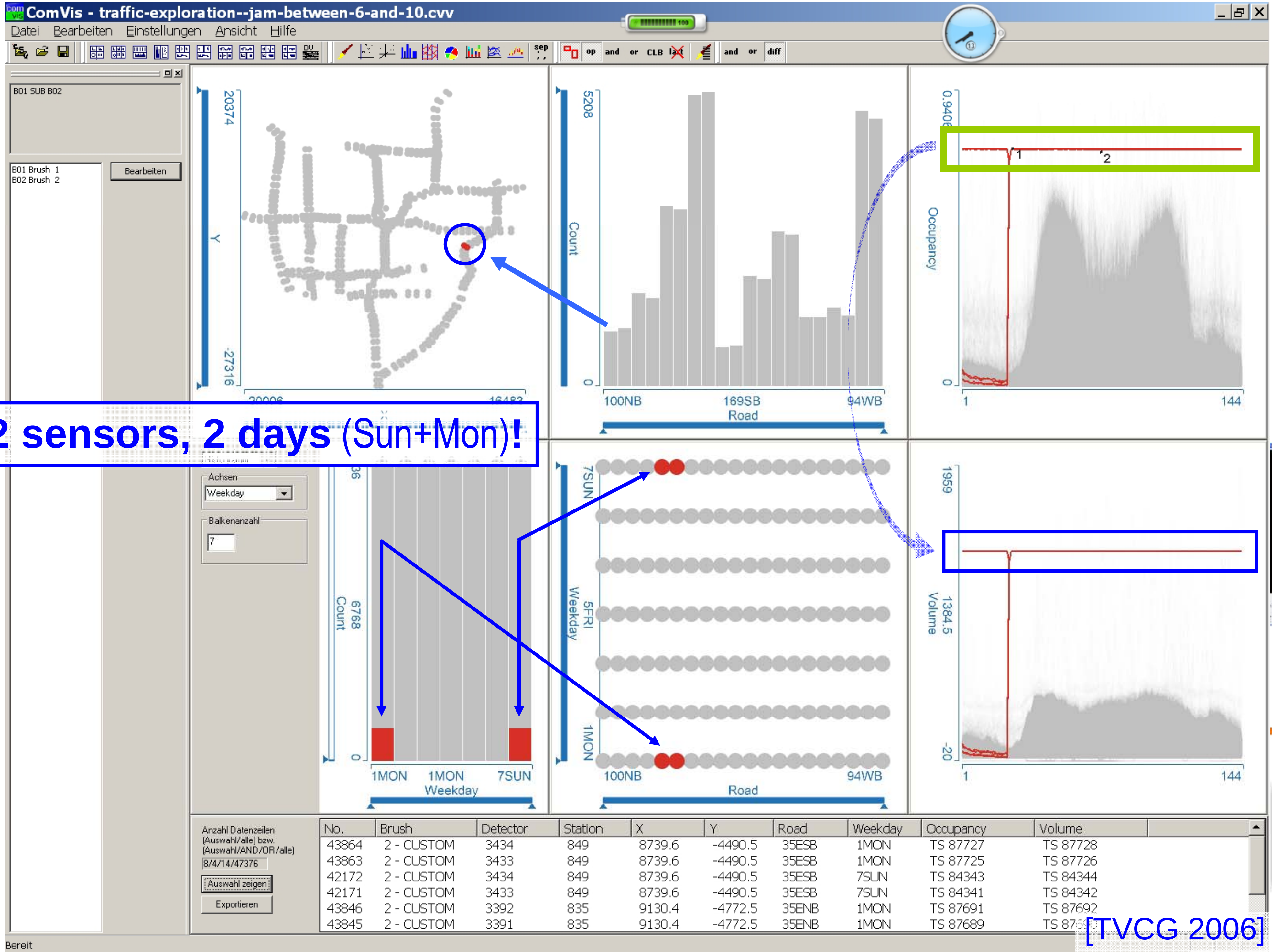


Traffic Sensor Network

(Minneapolis, St. Pauls)

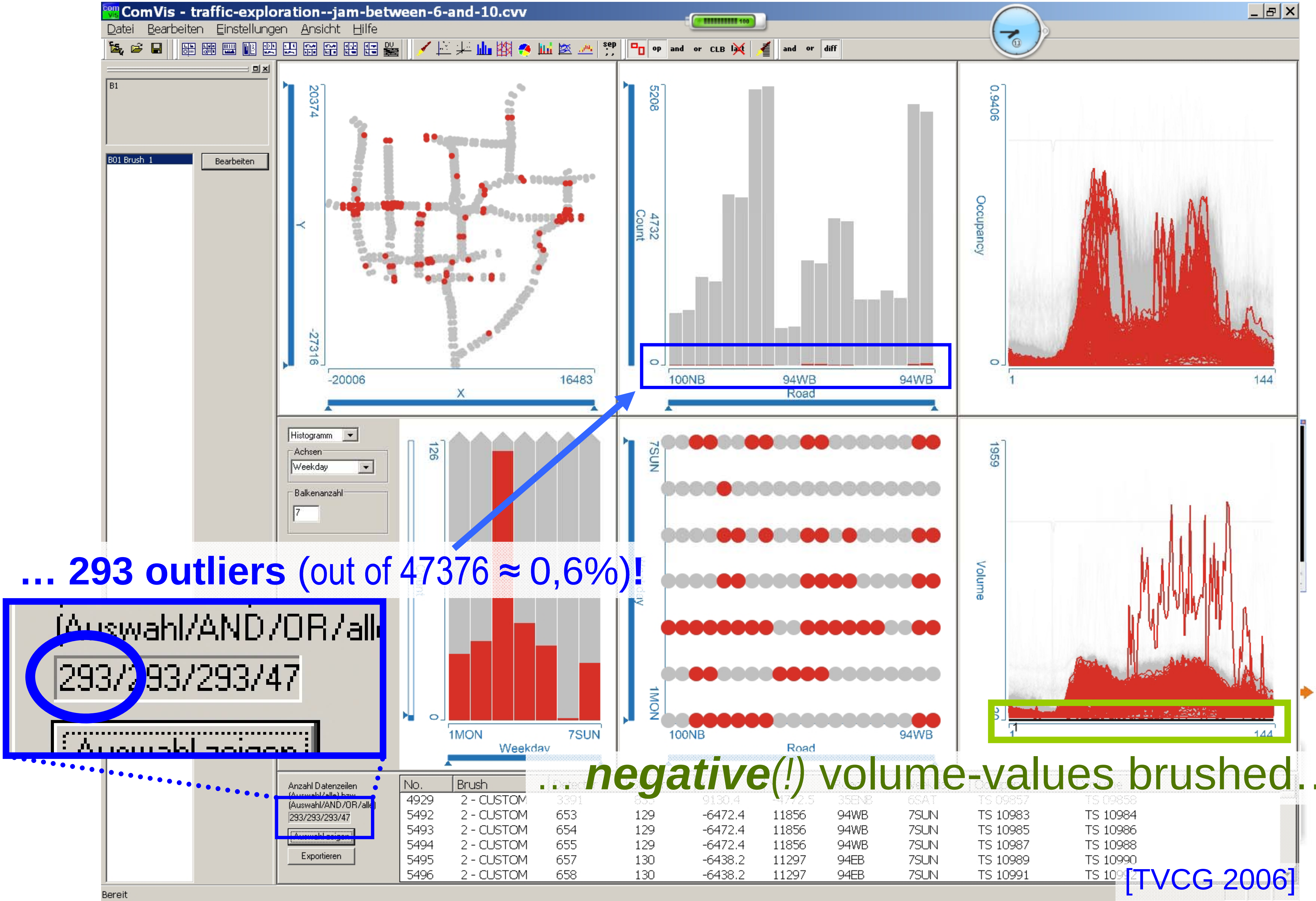
- **12 weeks** (84 days)
- **564 sensors**
- **daily data**,
  aggregated from measurements all 30 secs.
- 2· 47376 = **94752 graphs**
  (144 f(t)-values each, one per 10 mins.)

[TVCG 2006]



… 2 sensors, 2 days (Sun+Mon)**!**

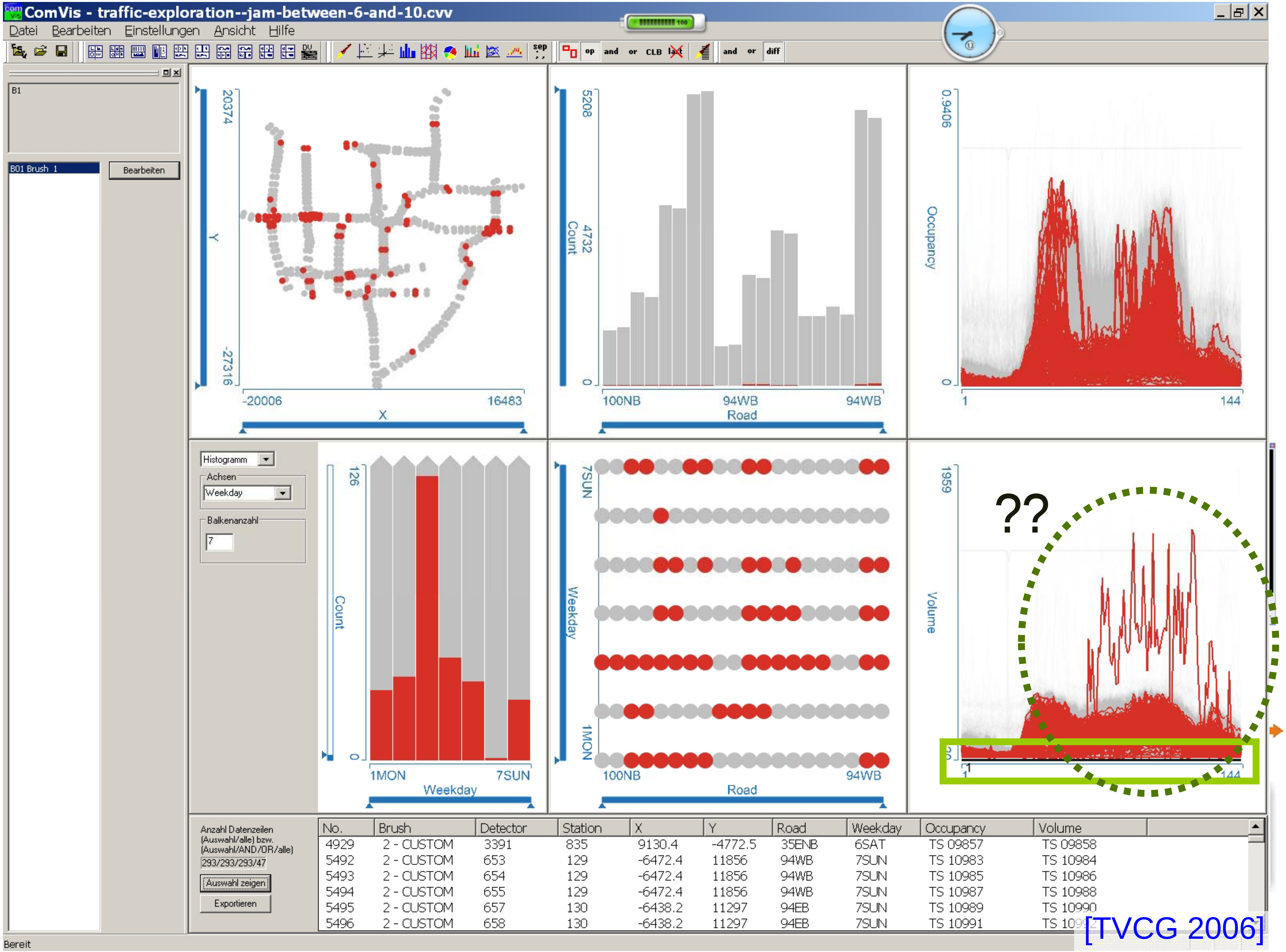
[TVCG 2006]



… **293 outliers** (out of 47376 ≈ 0,6%)!

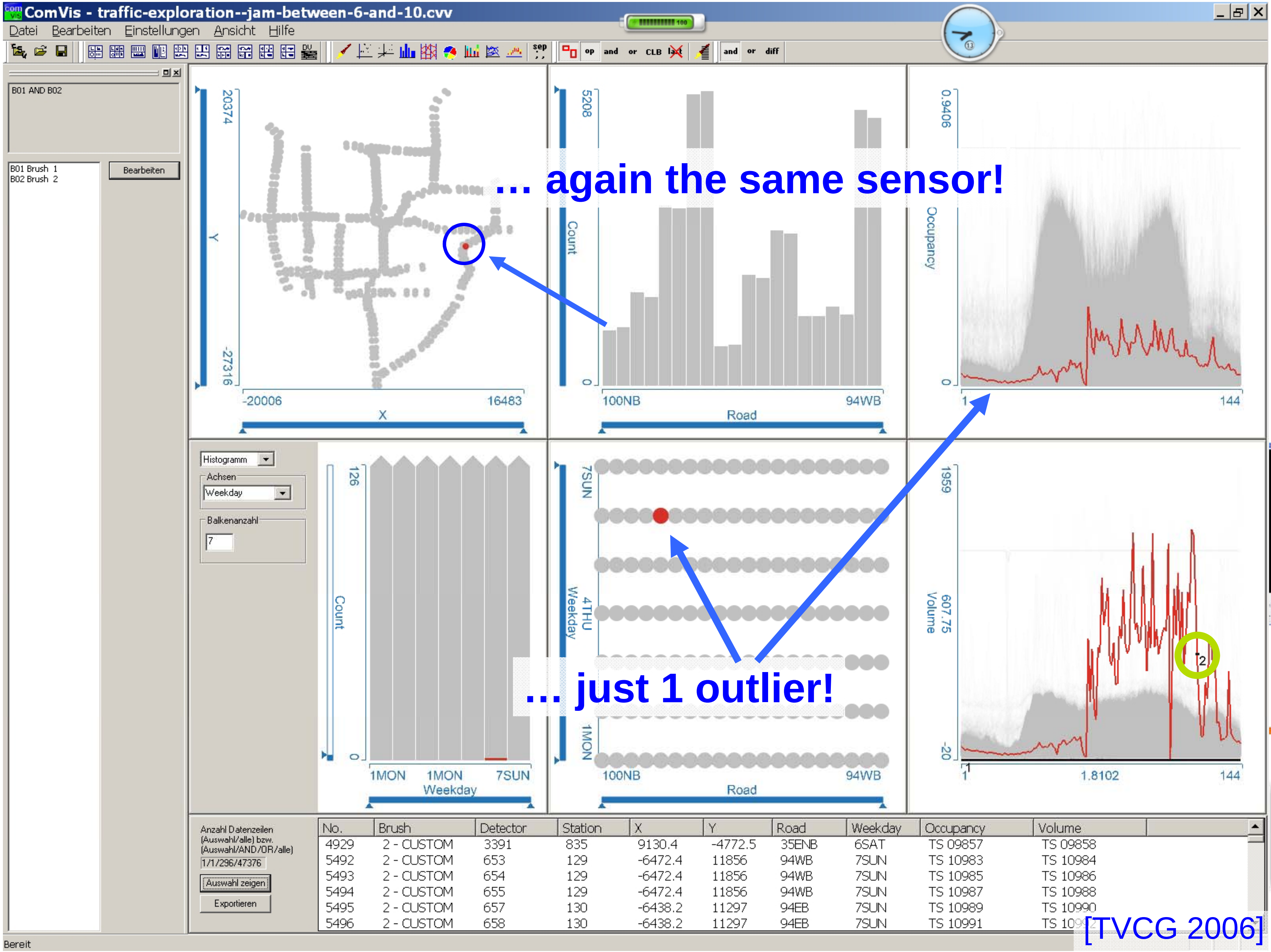
… ***negative***(!) volume-values brushed…

[TVCG 2006]

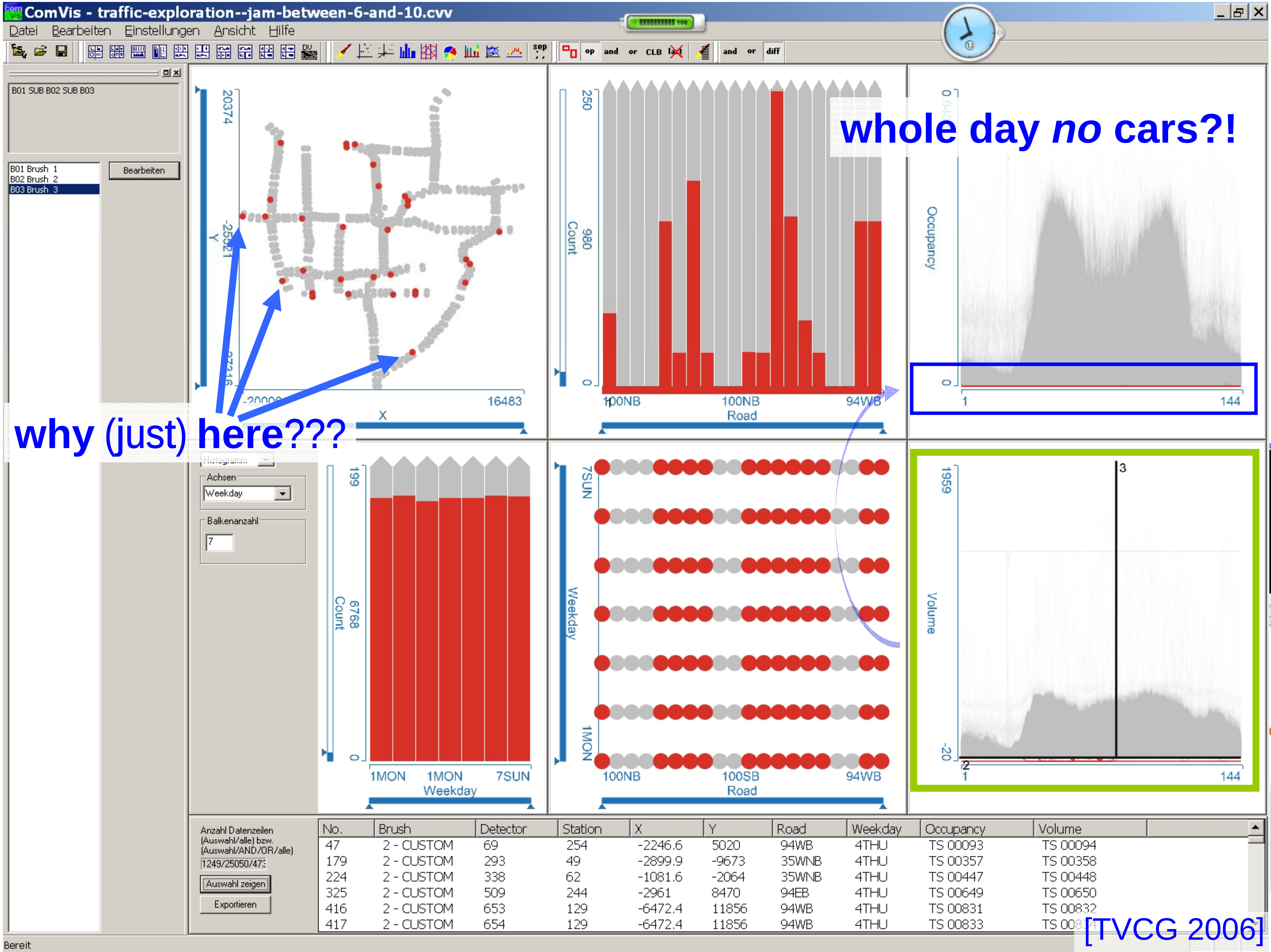


No.	Brush	Detector	Station	X	Y	Road	Weekday	Occupancy	Volume
4929	2 - CUSTOM	3391	835	9130.4	-4772.5	35ENB	6SAT	TS 09857	TS 09858
5492	2 - CUSTOM	653	129	-6472.4	11856	94WB	7SUN	TS 10983	TS 10984
5493	2 - CUSTOM	654	129	-6472.4	11856	94WB	7SUN	TS 10985	TS 10986
5494	2 - CUSTOM	655	129	-6472.4	11856	94WB	7SUN	TS 10987	TS 10988
5495	2 - CUSTOM	657	130	-6438.2	11297	94EB	7SUN	TS 10989	TS 10990
5496	2 - CUSTOM	658	130	-6438.2	11297	94EB	7SUN	TS 10991	TS 10992

[TVCG 2006]


ComVis - traffic-exploration--jam-between-6-and-10.cvv
Datei Bearbeiten Einstellungen Ansicht Hilfe
B01 AND B02
B01 Brush 1
B02 Brush 2
Bearbeiten
... again the same sensor!
20374
Y
-27316
-20006
16483
X
5208
Count
0
100NB
94WB
Road
0.9406
Occupancy
0
1
144
Histogramm
Achsen
Weekday
Balkenanzahl
7
126
Count
0
1MON 1MON 7SUN
Weekday
7SUN
4THU
Weekday
1MON
100NB
94WB
Road
1959
607.75
Volume
-20
1
1.8102
144
... just 1 outlier!
Anzahl Datenzeilen (Auswahl/alle) bzw. (Auswahl/AND/OR/alle)
1/1/296/47376
Auswahl zeigen
Exportieren
No. Brush Detector Station X Y Road Weekday Occupancy Volume
4929 2 - CUSTOM 3391 835 9130.4 -4772.5 35ENB 6SAT TS 09857 TS 09858
5492 2 - CUSTOM 653 129 -6472.4 11856 94WB 7SUN TS 10983 TS 10984
5493 2 - CUSTOM 654 129 -6472.4 11856 94WB 7SUN TS 10985 TS 10986
5494 2 - CUSTOM 655 129 -6472.4 11856 94WB 7SUN TS 10987 TS 10988
5495 2 - CUSTOM 657 130 -6438.2 11297 94EB 7SUN TS 10989 TS 10990
5496 2 - CUSTOM 658 130 -6438.2 11297 94EB 7SUN TS 10991
Bereit

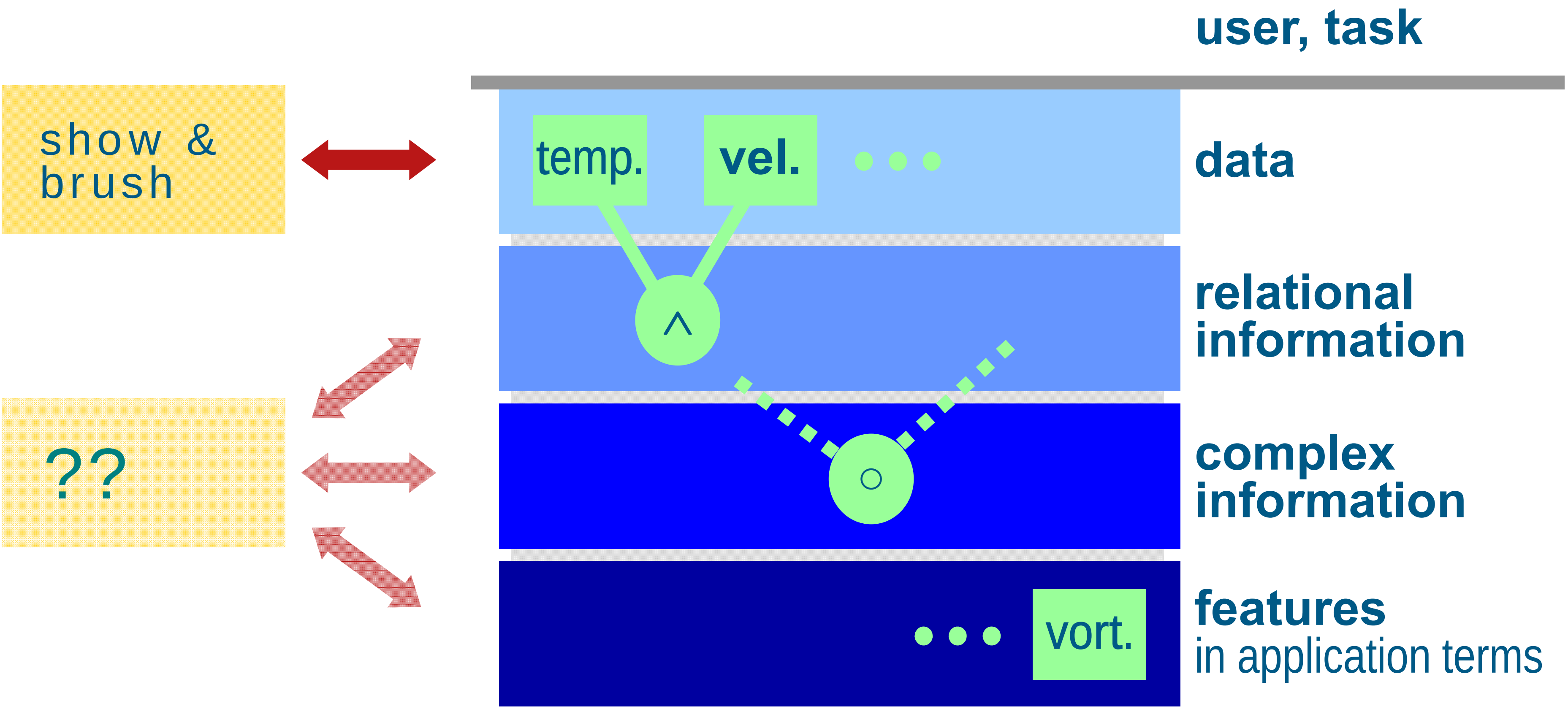
[TVCG 2006]



No.	Brush	Detector	Station	X	Y	Road	Weekday	Occupancy	Volume
47	2 - CUSTOM	69	254	-2246.6	5020	94WB	4THU	TS 00093	TS 00094
179	2 - CUSTOM	293	49	-2899.9	-9673	35WNB	4THU	TS 00357	TS 00358
224	2 - CUSTOM	338	62	-1081.6	-2064	35WNB	4THU	TS 00447	TS 00448
325	2 - CUSTOM	509	244	-2961	8470	94EB	4THU	TS 00649	TS 00650
416	2 - CUSTOM	653	129	-6472.4	11856	94WB	4THU	TS 00831	TS 00832
417	2 - CUSTOM	654	129	-6472.4	11856	94WB	4THU	TS 00833	TS 00[illegible]

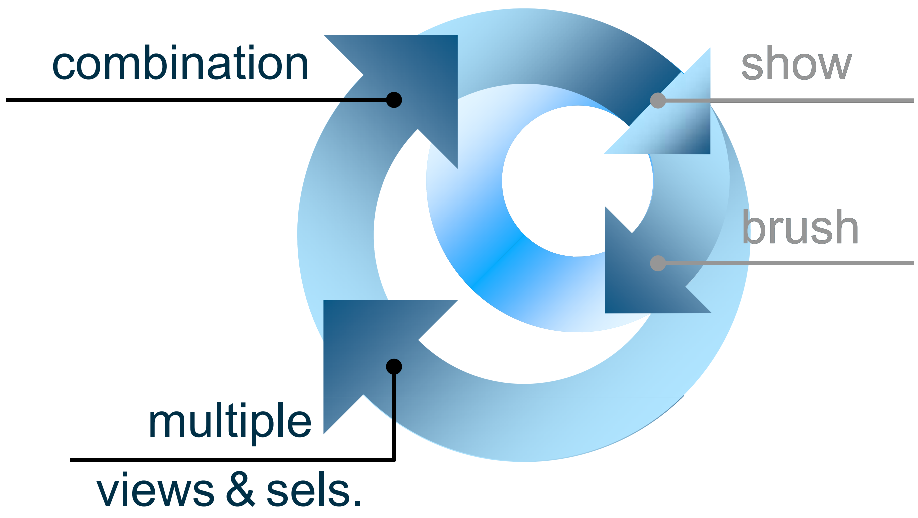
A Layered Information Space

- Metaphor of a “sea of information”
- Explicitly represented information (the data) on top, implicitly represented information below (in layers)



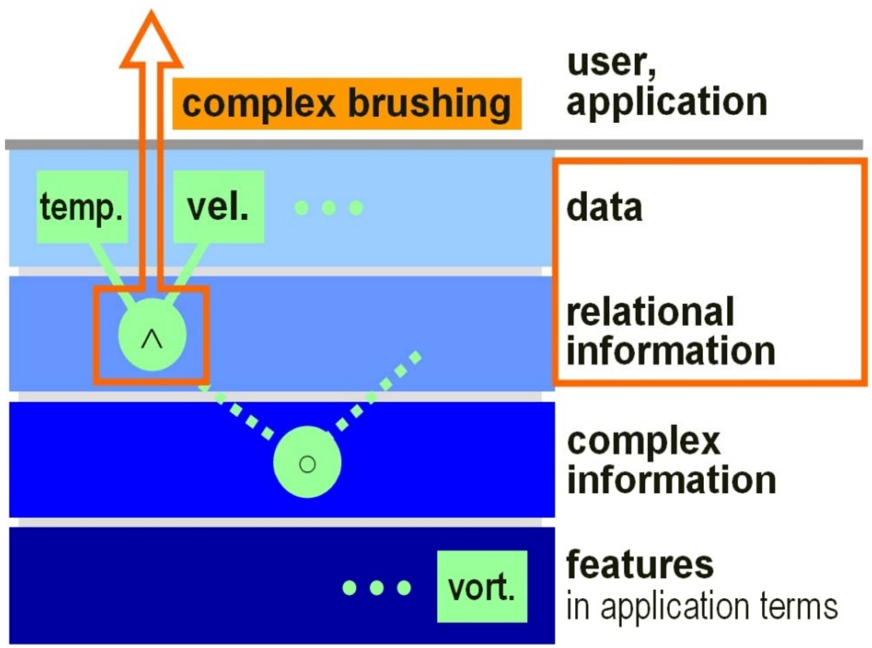
Relational Analysis (IVA level 2)

- **Extended IVA loop**
  - **iterative & relational exploration / analysis**
  - **read between the lines** (implicitly represented inform.)



A typical continuation of an IVA session:

- bring up more views
- add/combine brushes
- focus the analysis, drill deeper!



Relational Analysis (IVA level 2)

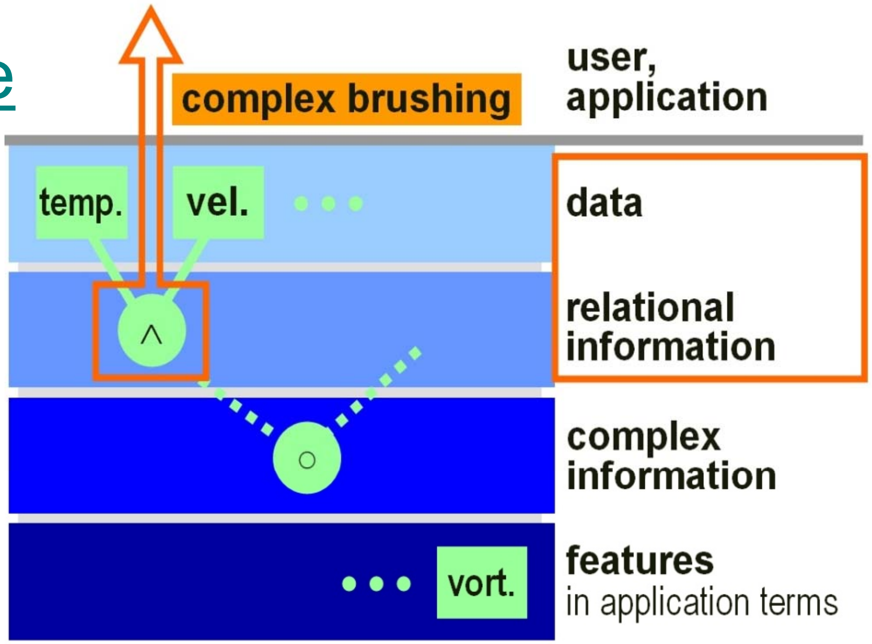
- **Extended IVA loop**
  - **iterative & relational exploration / analysis**
  - **read between the lines** (implicitly represented inform.)
- **Requires**:
  - multiple views
  - feature definition language
  - multiple levels of F+C vis.

… the example of IVA again** (now level 2) **…

- Allows deep(er) information drill-down

A typical continuation of an IVA session:

- bring up more views
- add/combine brushes
- focus the analysis, drill deeper!

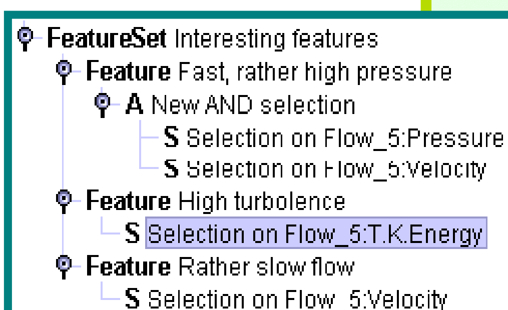


IVA: Feature Definition Language

- **Explicitly represented degree of interest** (DOI)
  DOI: additional (synthetic) data dimension(s)
- **Brushing** results in **DOI attribution**(s),
  relational analysis through multiple brushes
- **Tree** structure through **logical operators**
  - root, level 0 (OR node): set of features
  - level 1 (AND node(s)): feature specifications
  - … (individual brushes)
- Compare to:
  - natural language
  - DB query
- In/out: XML

Example:

interesting are …
flow regions where
pressure is high
AND velocity is high

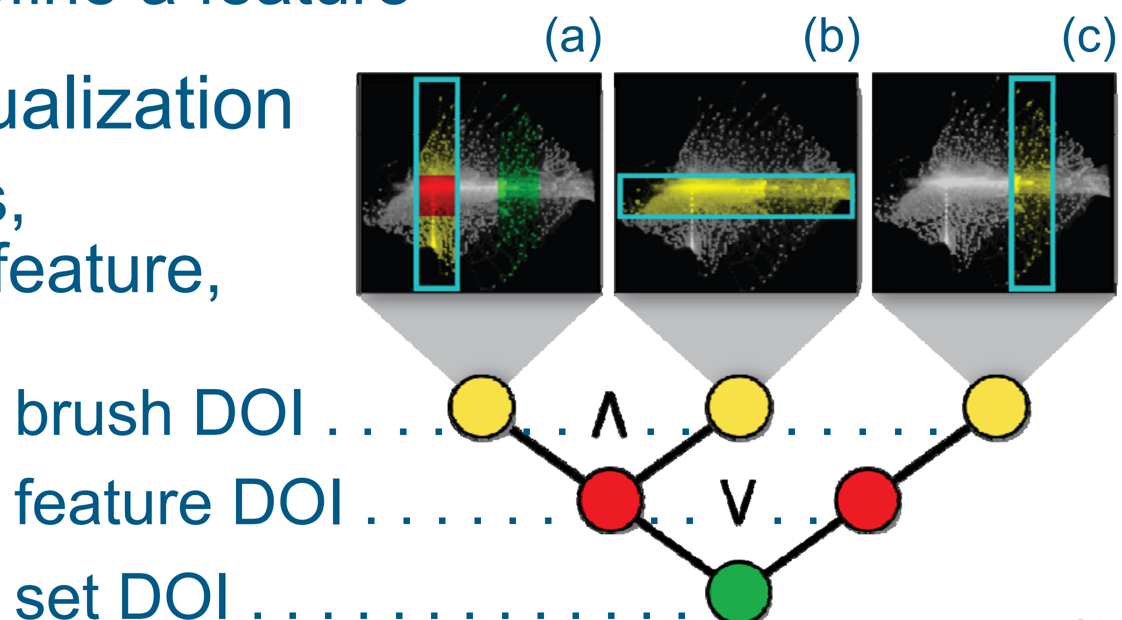


IVA: Four Levels of F+C Visualization

- In **show & brush**: one brush (focus), rest is context
  - data in focus: colored, less transparent
  - data in context: gray-scale, in background
- In **relational analysis**:
  - multiple features in a feature set (below top node)
  - multiple views define a feature

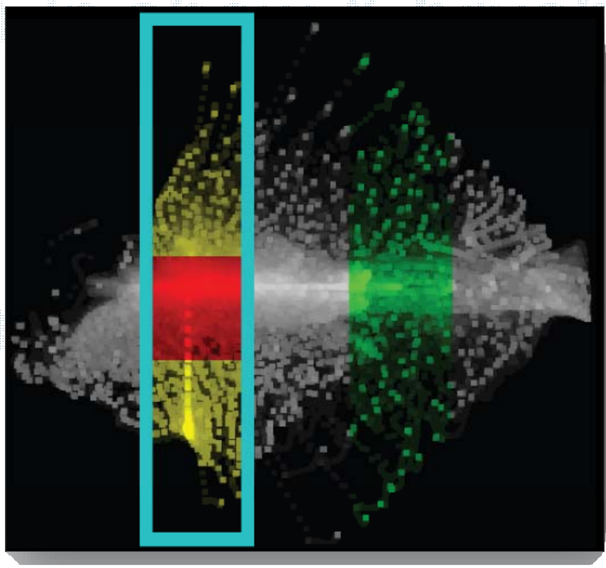
⇨ advanced F+C visualization

- here: three views,
  two (a, b) for one feature,
  one (c) for one
  other…



[Muigg et al., ’08]

IVA: Four Levels of F+C Visualization



gray: overall context

green: other features **(in the set)**

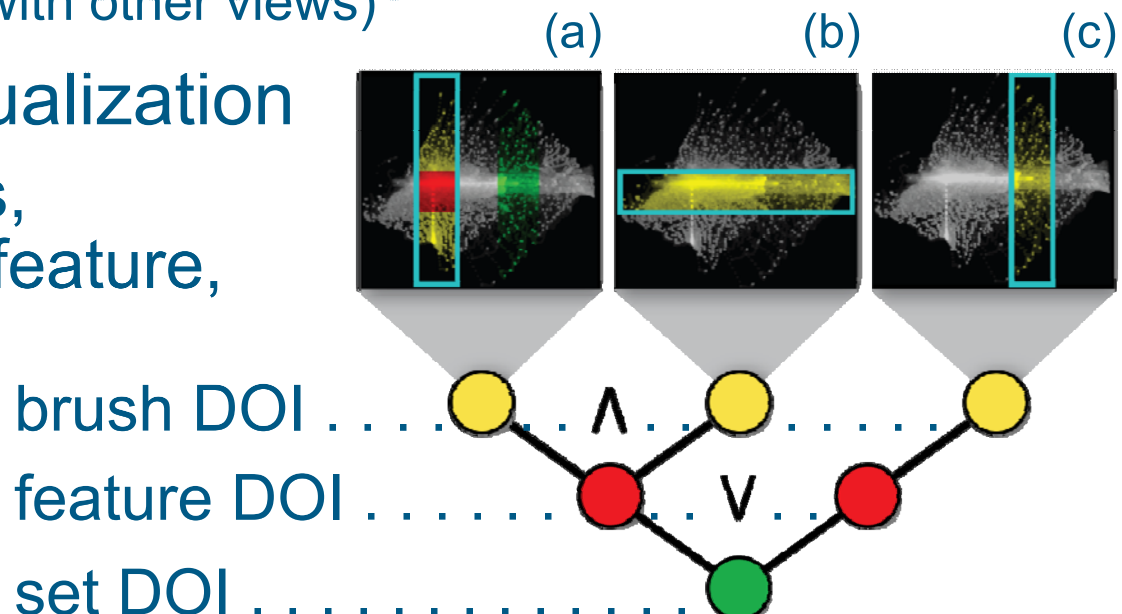
red: feature defined with this view
(and possibly with others, too)

yellow: brushed in this view, but not part of feature (only in combination with other views)

⇨ advanced F+C visualization

- here: three views, two (a, b) for one feature, one (c) for one other.

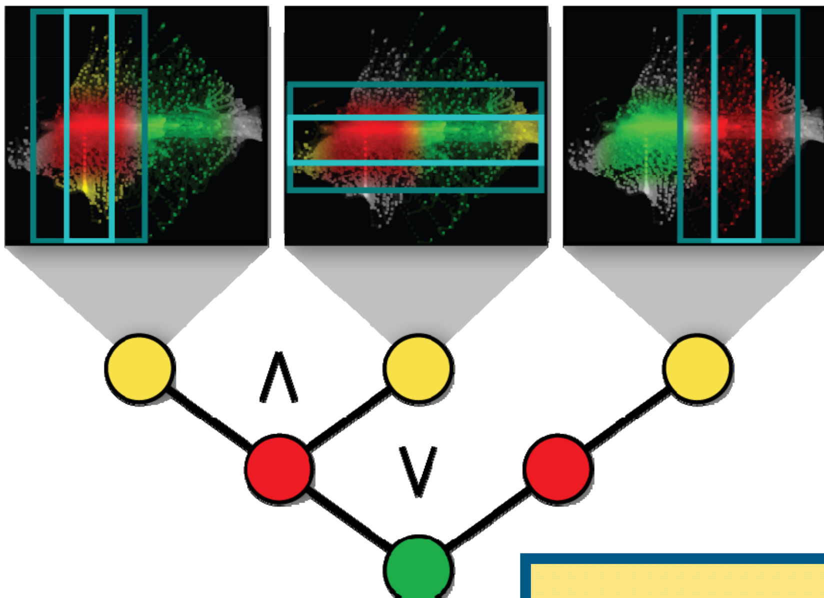
but how to color in combination with smooth brushing?

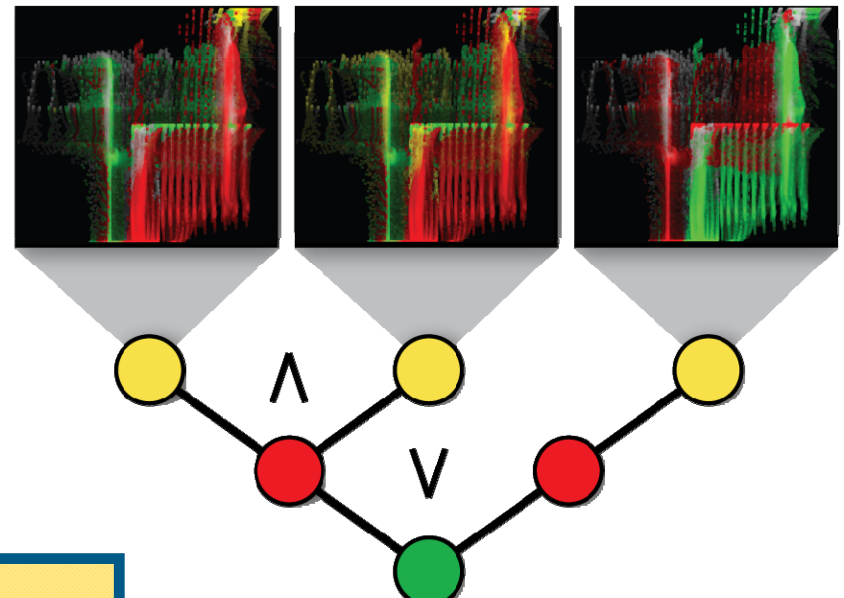


[Muigg et al., '08]

IVA: Coloring Complex DOI Combinations

- How to combine colors, when fractional DOI values overlap?
- How to combine colors, when many data items make one pixel?



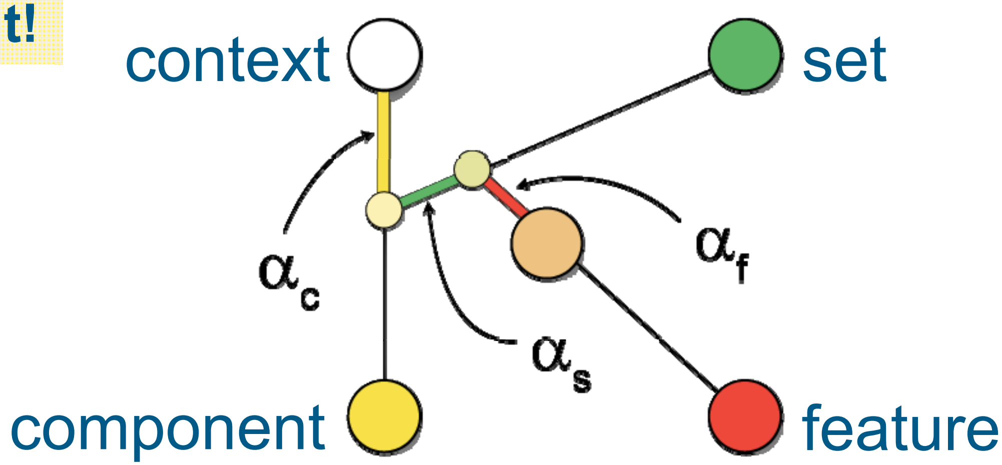


why brown??

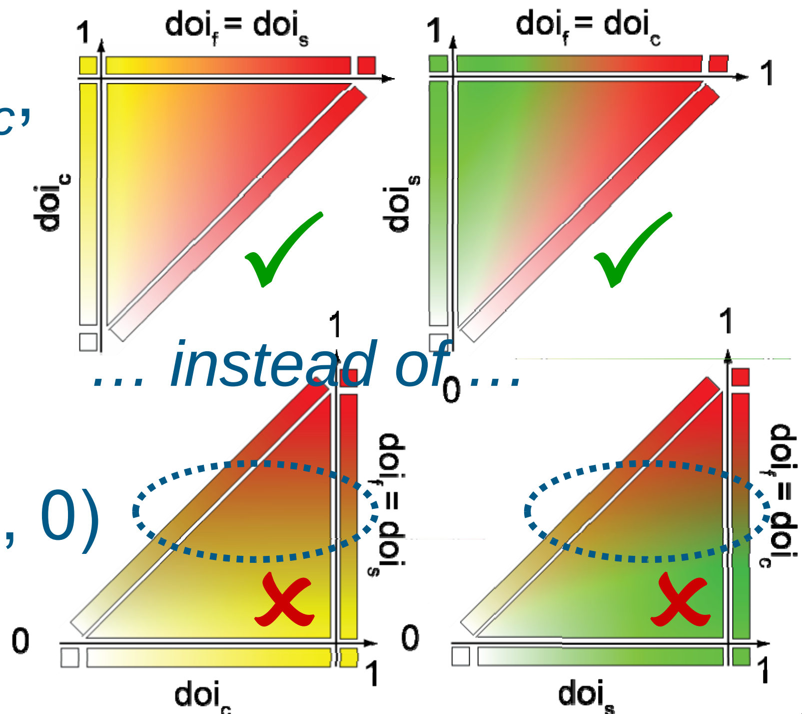
- Simple color mixing (convex combination of RGB values) does not do it!

IVA: Coloring Complex DOI Combinations

- Color:= most important!
  - red over (
  - green over (
  - yellow over
  - gray))

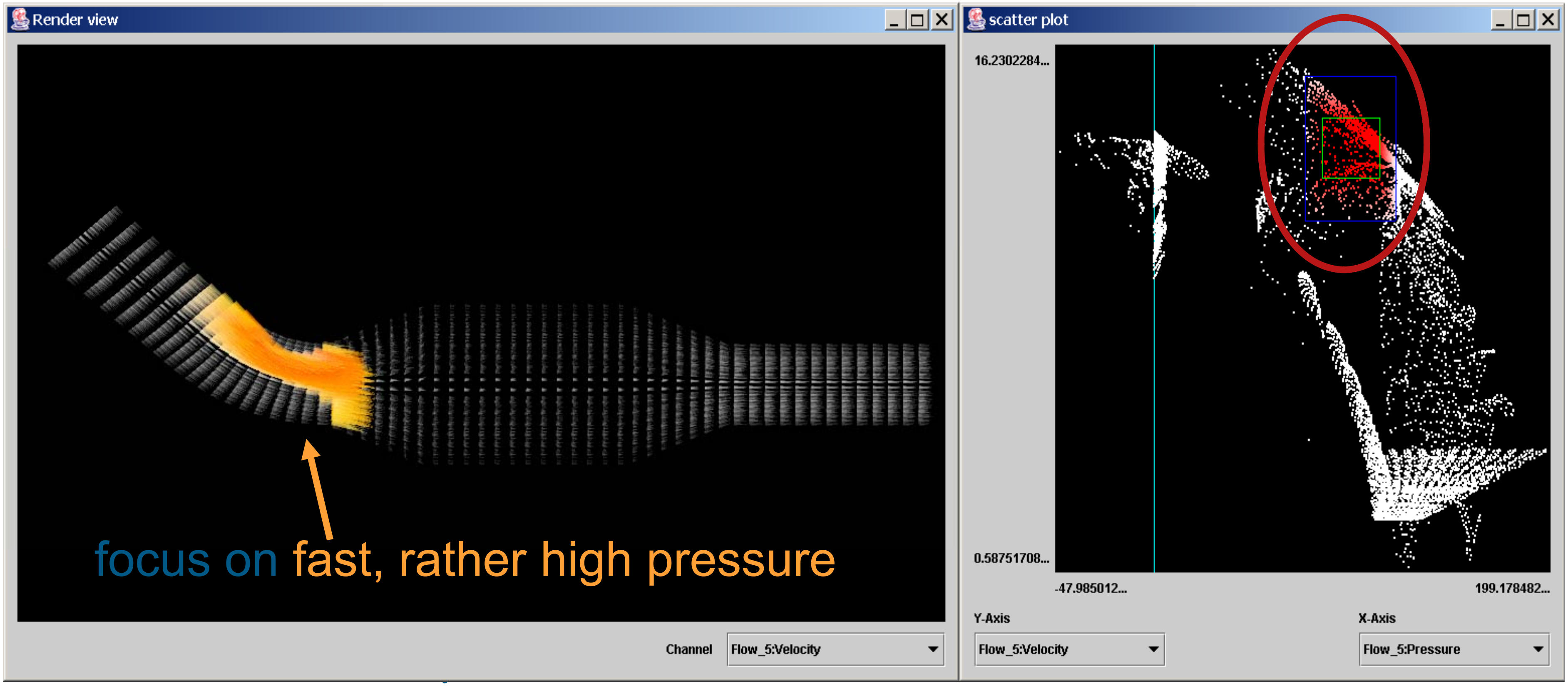


- Blending weights α_f, α_s, and α_c, with
  - α_f = feature DOI
  - α_s = set DOI – feature DOI
    // only the rest here!
  - α_c = max(comp. DOI – set DOI, 0)
    // only non-hidden parts!



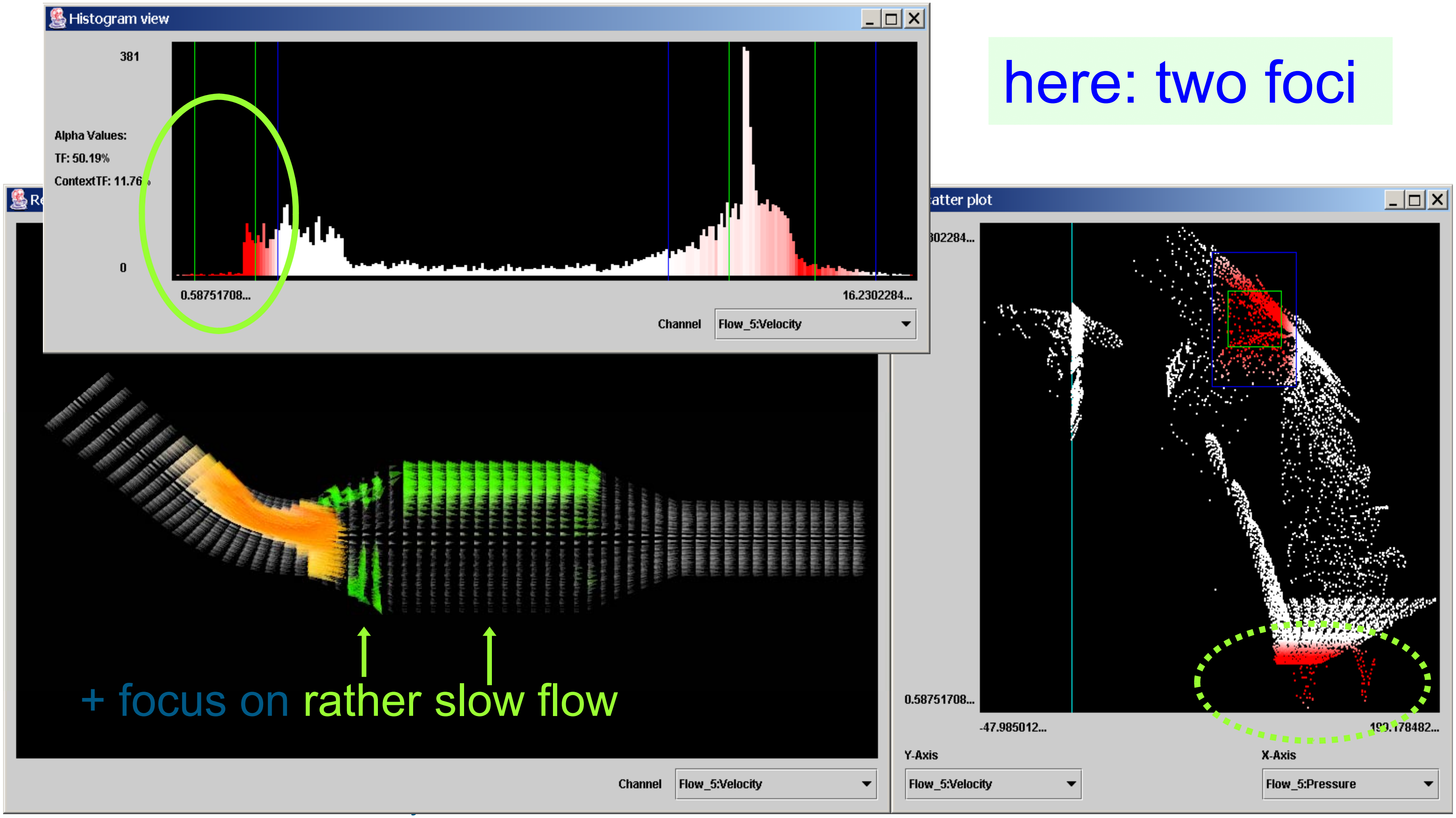
IVA Example (repeated from level 1)

- Two views (domain, range), one brush
  - simple feature localization
  - here: fast, mid-large pressure



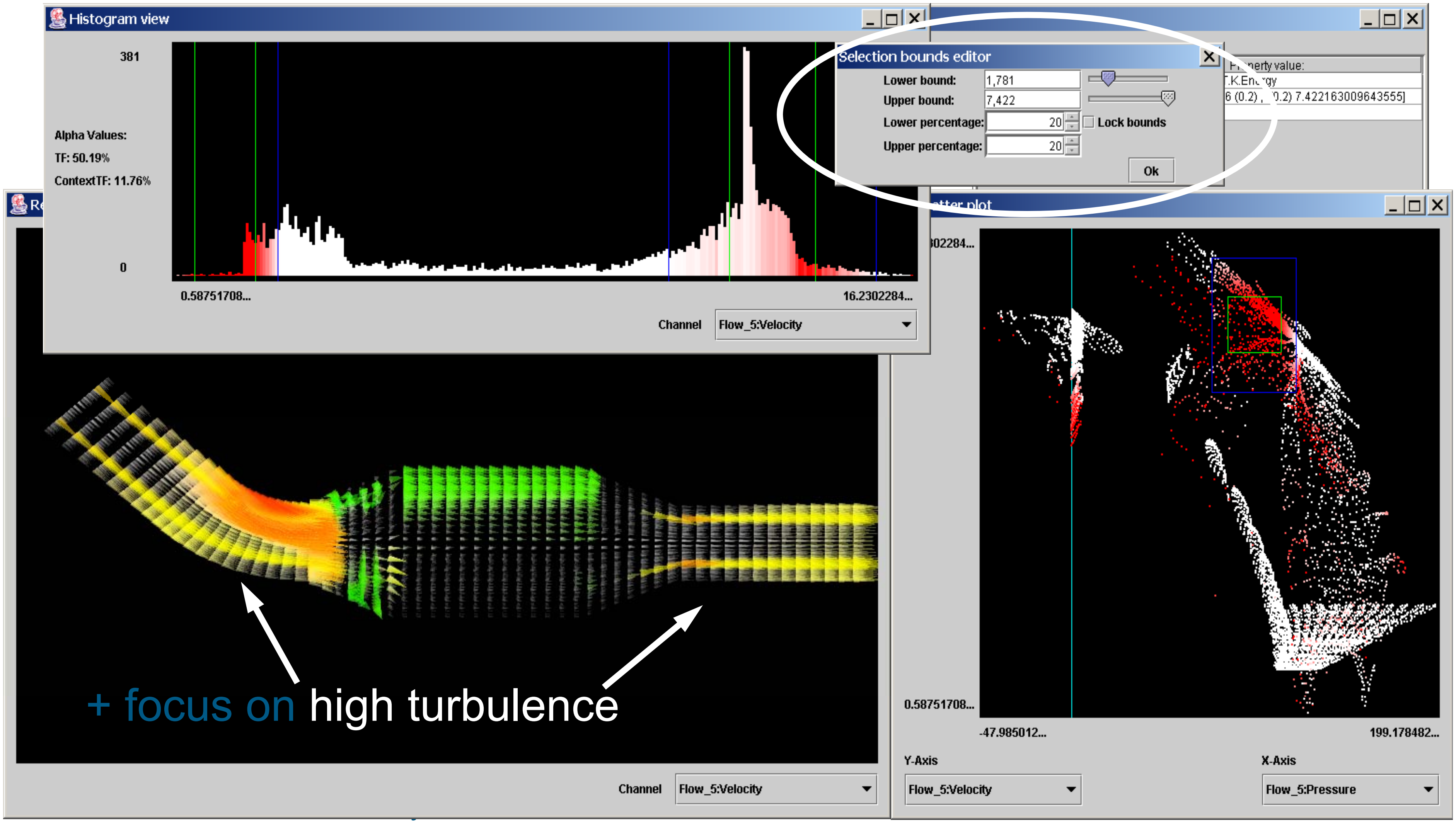
IVA Example, going level 2

- More views, more brushes, logical combinations



IVA Example, level 2

- Three brushes, complementary F+C vis., FDL



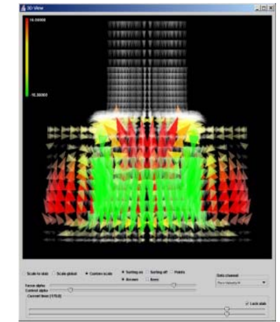
Iterative Exploration / Analysis

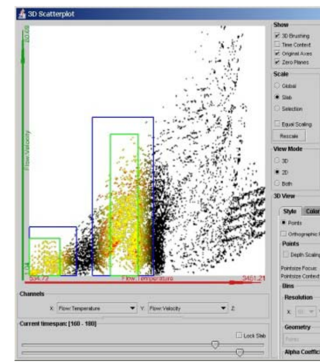
all steps

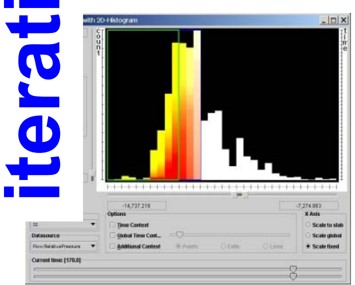
main direction of work ⇓

- SciVis (overview, orientation)
- New View (InfoVis)
- Adjust Projection (InfoVis)
- Brush InfoVis-view
- Linked Visualization
  - Alter Brush
  - Add Brush (→ compound brush)
  - Add View (InfoVis)
- (presentation, report, …)

iterative refinement







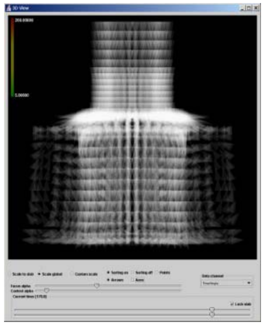
IVA: Iterative Exploration / Analysis

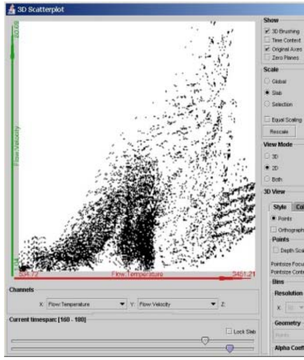
the start

main direction of work ⇓

- SciVis (overview, orientation)
- New View (InfoVis)
- Adjust Projection (InfoVis)
- Brush InfoVis-view
- Linked Visualization
  - Alter Brush
  - Add Brush (→ compound brush)
  - Add View (InfoVis)
- (presentation, report, …)

iterative refinement





IVA: Iterative Exploration / Analysis

analysis

main direction of work ⇓

SciVis (overview, orientation)

New View (InfoVis)

Adjust Projection (InfoVis)

Brush InfoVis-view

Linked Visualization

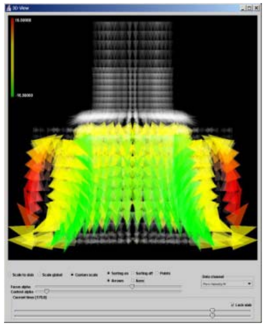
Alter Brush

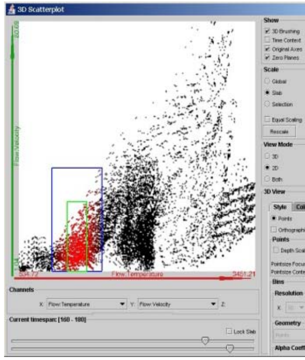
Add Brush (→ compound brush)

Add View (InfoVis)

(presentation, report, …)

iterative refinement





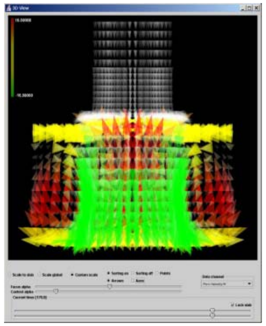
IVA: Iterative Exploration / Analysis

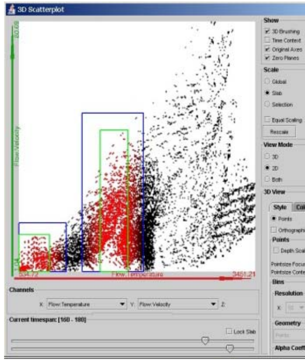
analysis

main direction of work ⇓

- SciVis (overview, orientation)
- New View (InfoVis)
- Adjust Projection (InfoVis)
- Brush InfoVis-view
- **Linked Visualization**
  - **Alter Brush**
  - **Add Brush (→ compound brush)**
  - Add View (InfoVis)
- (presentation, report, …)

iterative refinement





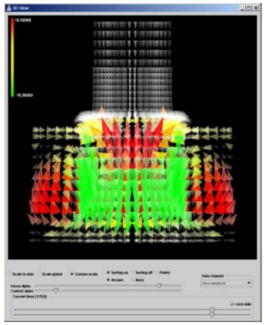
IVA: Iterative Exploration / Analysis

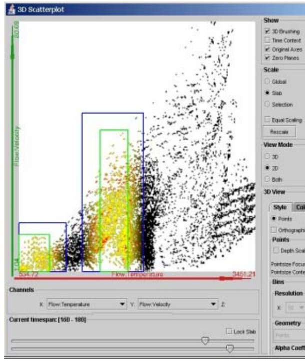
analysis

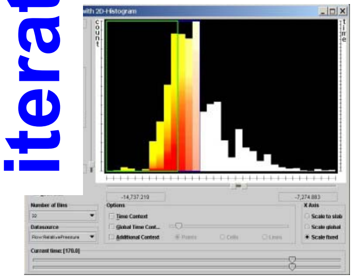
main direction of work ⇓

- SciVis (overview, orientation)
- New View (InfoVis)
- **Adjust Projection (InfoVis)**
- **Brush InfoVis-view**
- **Linked Visualization**
  - Alter Brush
  - Add Brush (→ compound brush)
  - **Add View (InfoVis)**
- (presentation, report, …)

iterative refinement







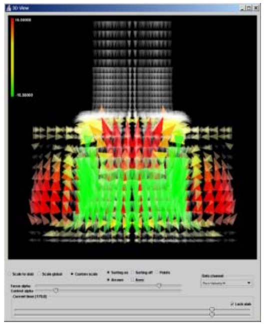
Iterative Exploration / Analysis

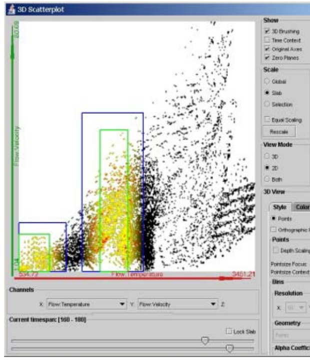
all steps

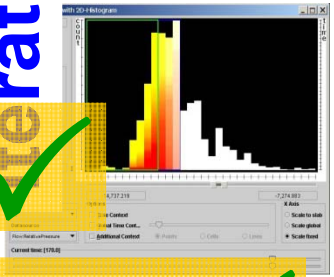
main direction of work

- **SciVis (overview, orientation)**
- **New View (InfoVis)**
- **Adjust Projection (InfoVis)**
- **Brush InfoVis-view**
- **Linked Visualization**
  - **Alter Brush**
  - **Add Brush (→ compound brush)**
  - Add View (InfoVis)
- (publication, report, ...)

iterative refinement







but how to capture features
which ***cannot*** be grasped
through data values
or logical combinations of them?

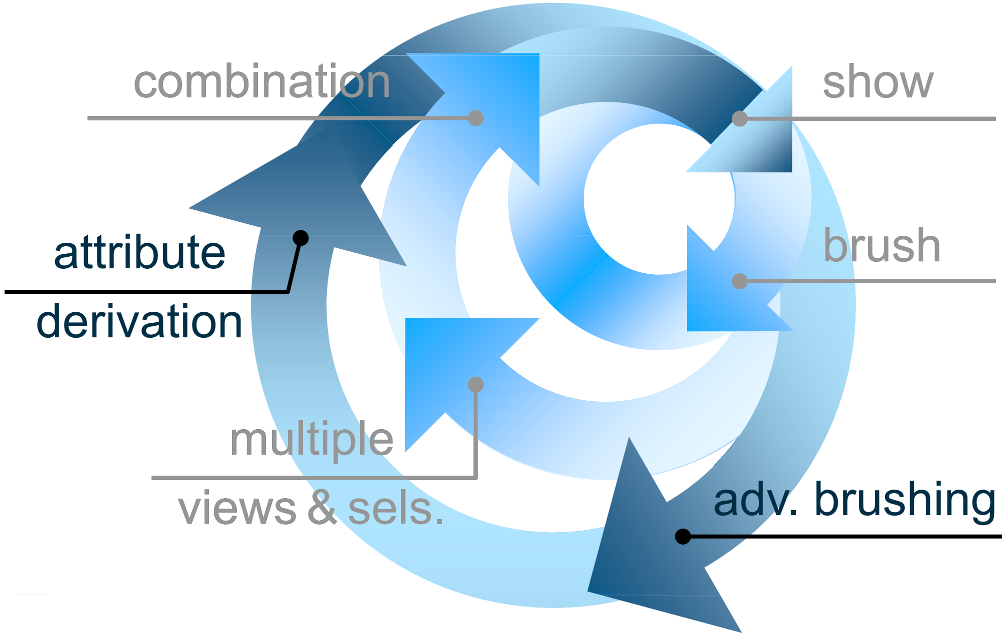
show & brush ✓

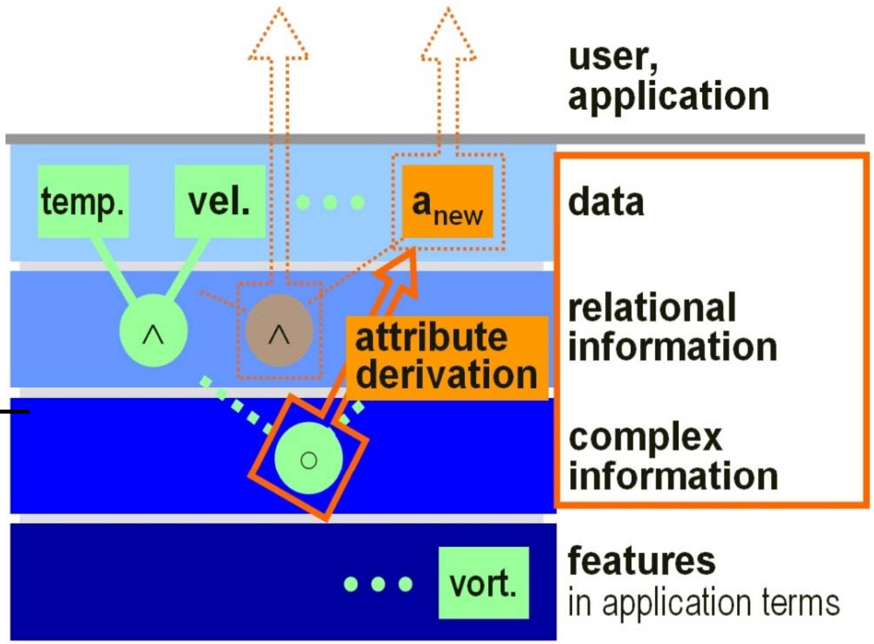
relational analysis ✓

Complex Analysis (IVA level 3)

- **Joining forces**:
  - integrate **computational analysis**
  - **extend brushing**

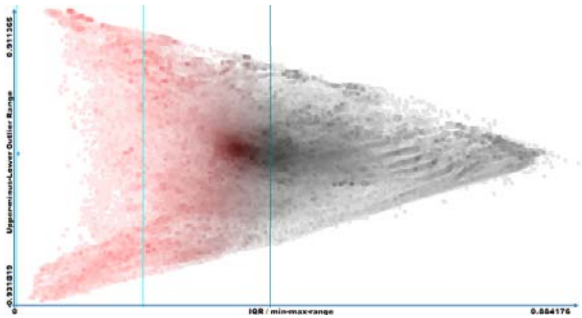
Boosting IVA:
- **derive information**
- **advanced brushes**
- access a new level of exploration / analysis!





Complex Analysis (IVA level 3)

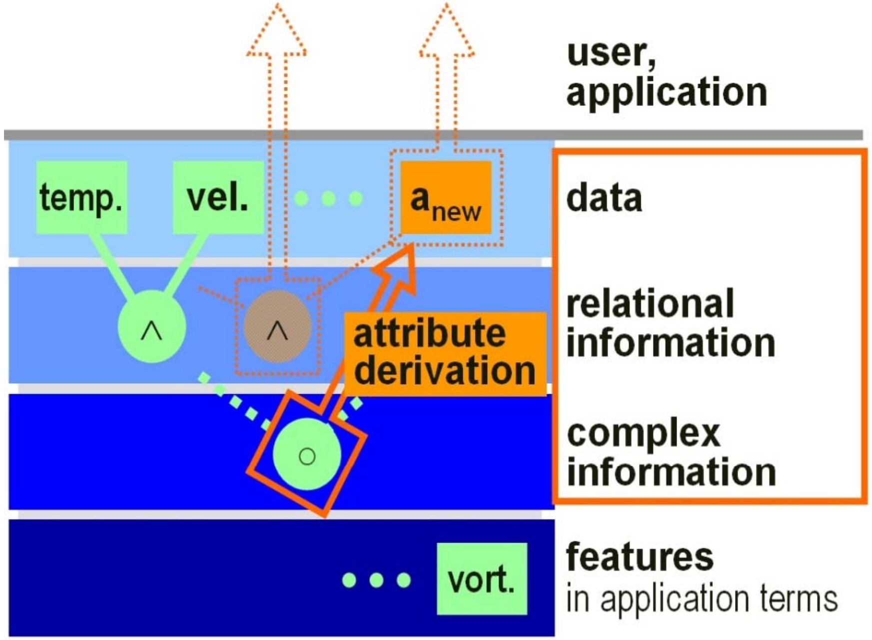
- **Joining forces**:
  - integrate **computational analysis**
  - **extend brushing**
- **Builds upon**:
  - advanced brushing
  - attribute derivation



- Very powerful analysis / exploration mechanism!

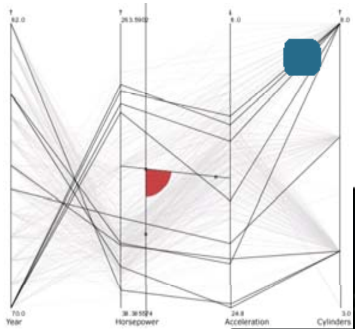
Boosting IVA:

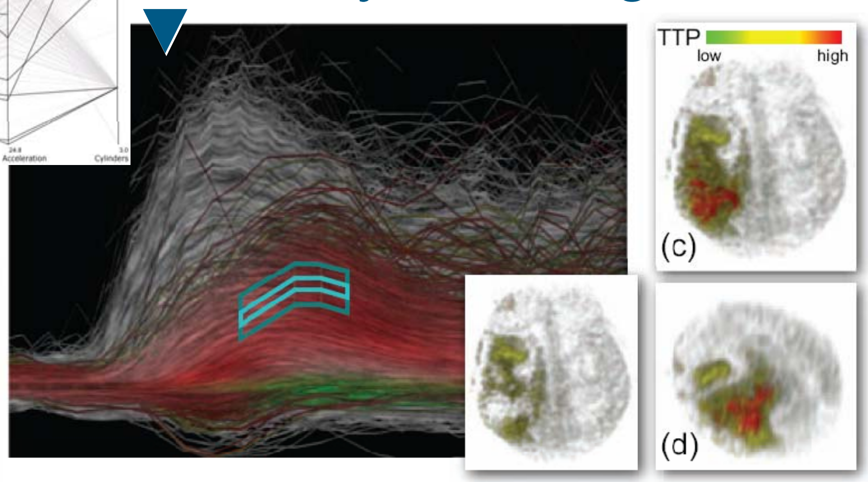
- **derive information**
- **advanced brushes**
- access a new level of exploration / analysis!

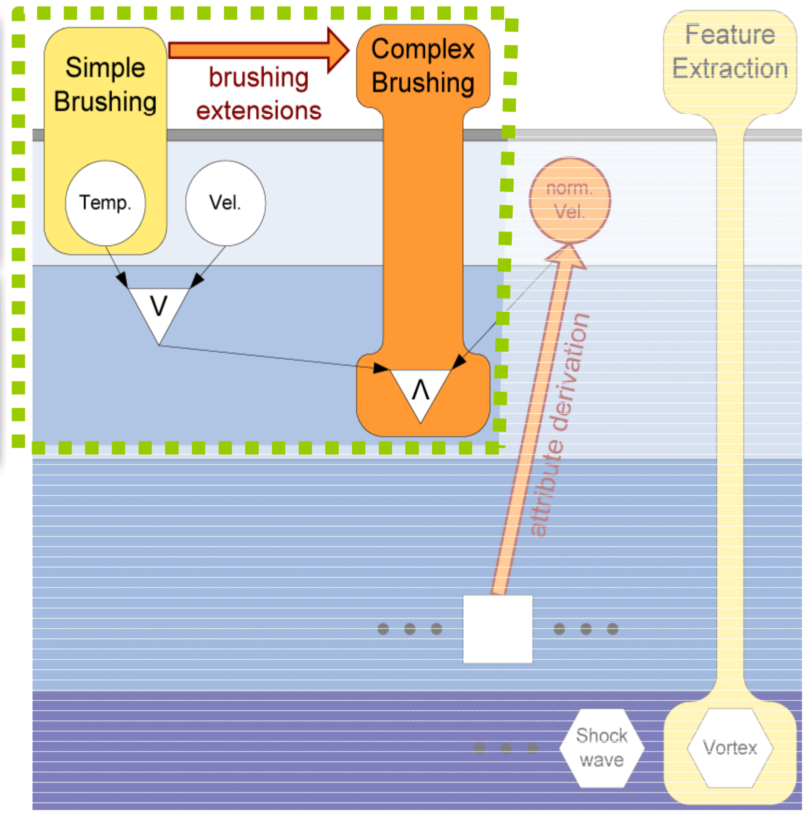


IVA: Advanced Brushing

- Two ways to get more out of IVA:
  - bring the data to the interaction (attribute derivation)
  - bring the interaction to the data (advanced brushing)
    - angular brushing [Hauser et al., 2002]
    - similarity brushing [Muigg et al., 2008]

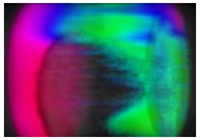






- Attribute derivation
  \+ advanced brushing
  = access to complex features

IVA: Attribute Derivation

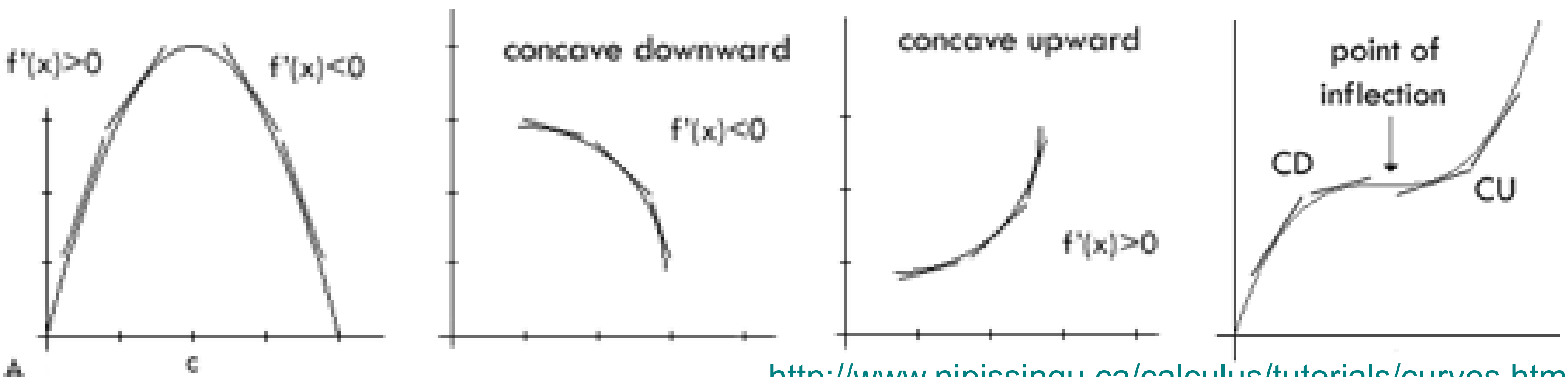


- Comprehensible ways to derive synthetic data dimensions from original data
  - data transformations
    - linear transformations
    - to log scale
    - etc.
  - derivative information (against the domain variables)
    - $\mathrm{d}\,d_i \,/\, \mathrm{d}\,\mathbf{x}$ – gradient information (wrt. space)
    - $\mathrm{d}\,d_i \,/\, \mathrm{d}\,t$ – change over time
  - relative information
    - data normalization
    - differences, ratios
  - model-related derivations
    - according to known relations, e.g., $\mathrm{div} = \nabla \cdot \mathbf{v}$

Curve Sketching

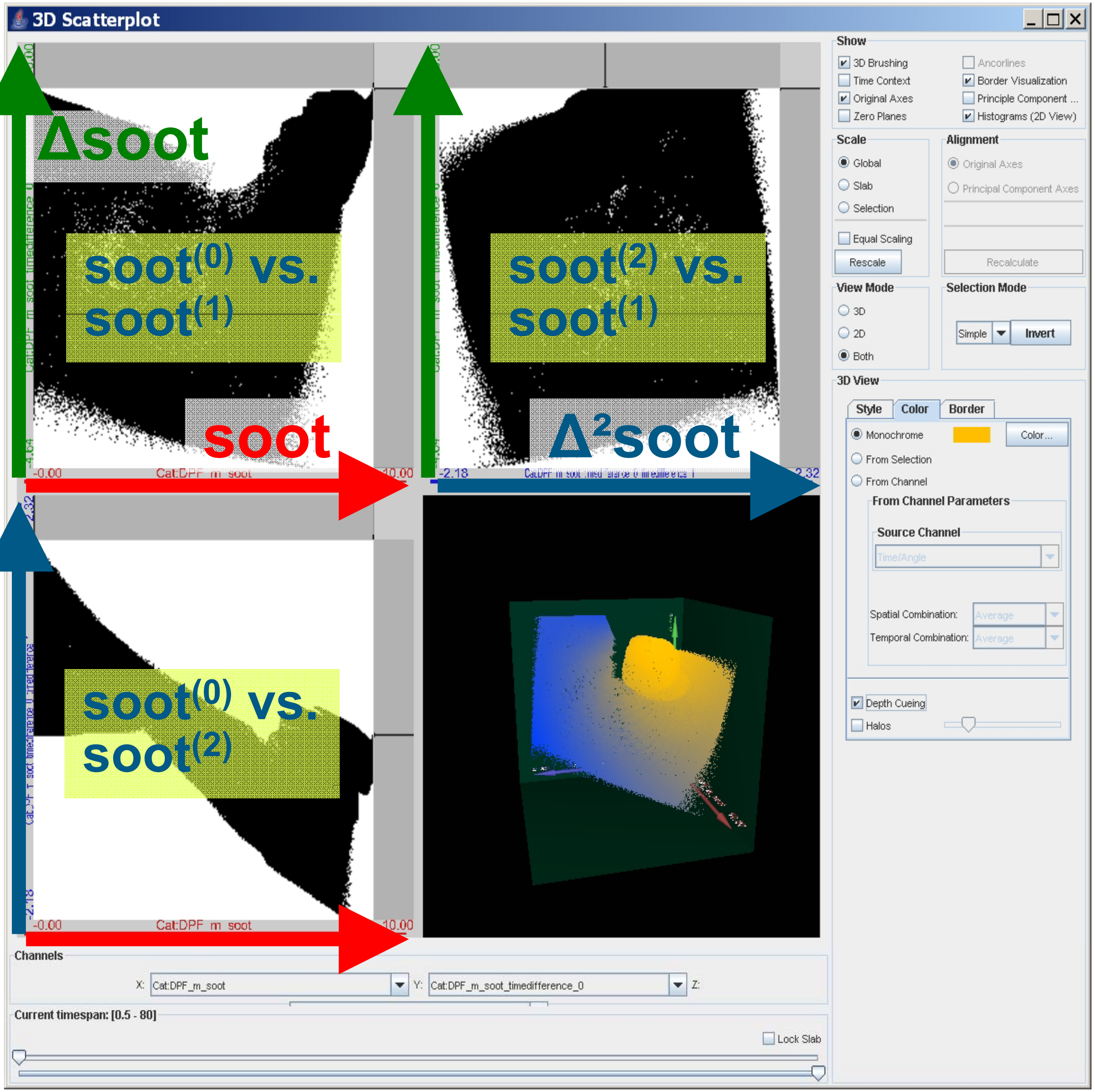
- Understanding function graphs:
  - special values of $f(x)$: zero, extremes, etc.
  - relative properties – positive/negative change $f'(x)$
    local maxima/minima – $f'(x) = 0$
  - double-relative properties: the change of change
    e.g., local maxima $\Leftrightarrow$ $f'(x) = 0$ & $f''(x) < 0$
    inflection point – $f''(x) = 0$

- Remember your days in school:

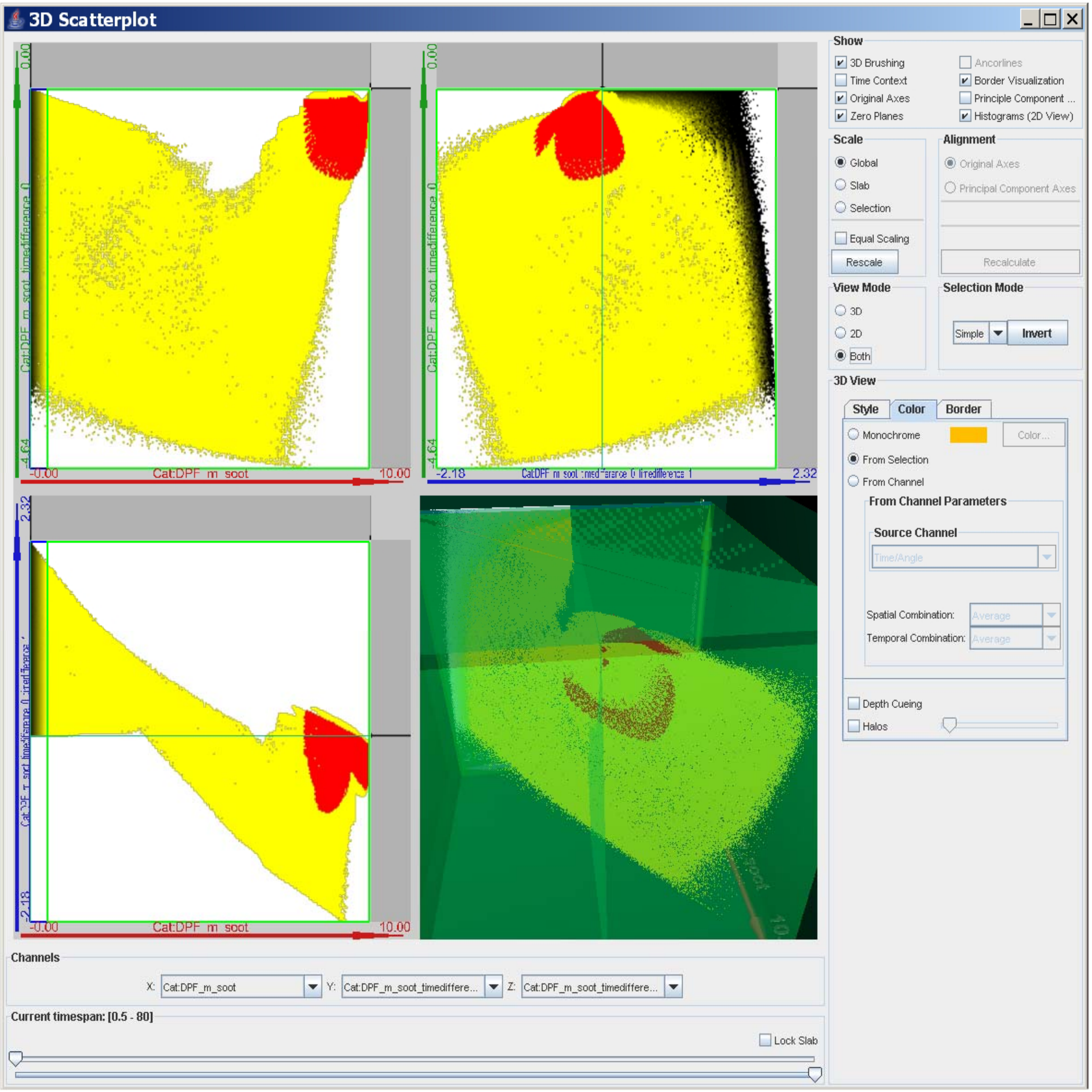


http://www.nipissingu.ca/calculus/tutorials/curves.html

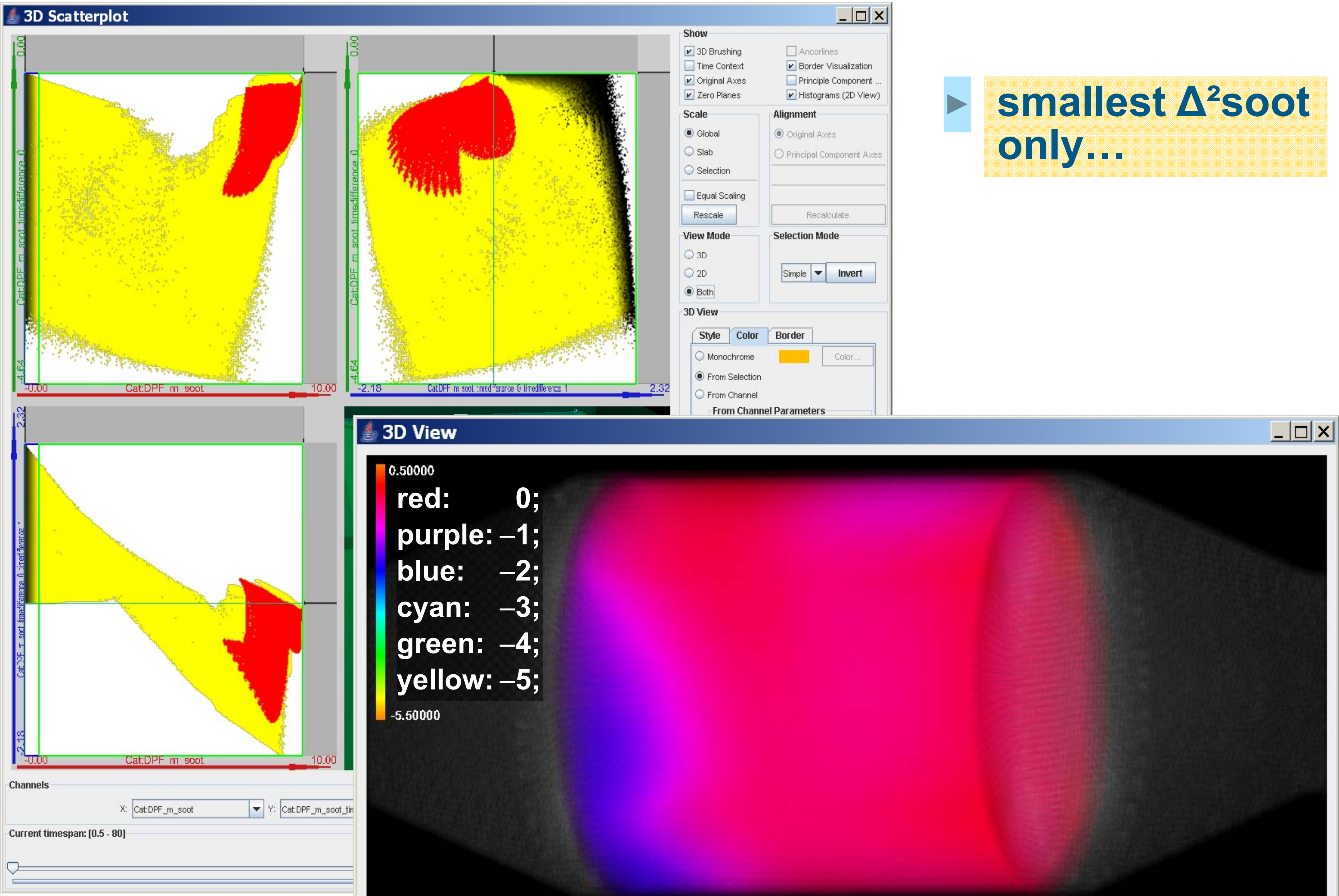
0-, 1st-, & 2nd-order Analysis



t=10s

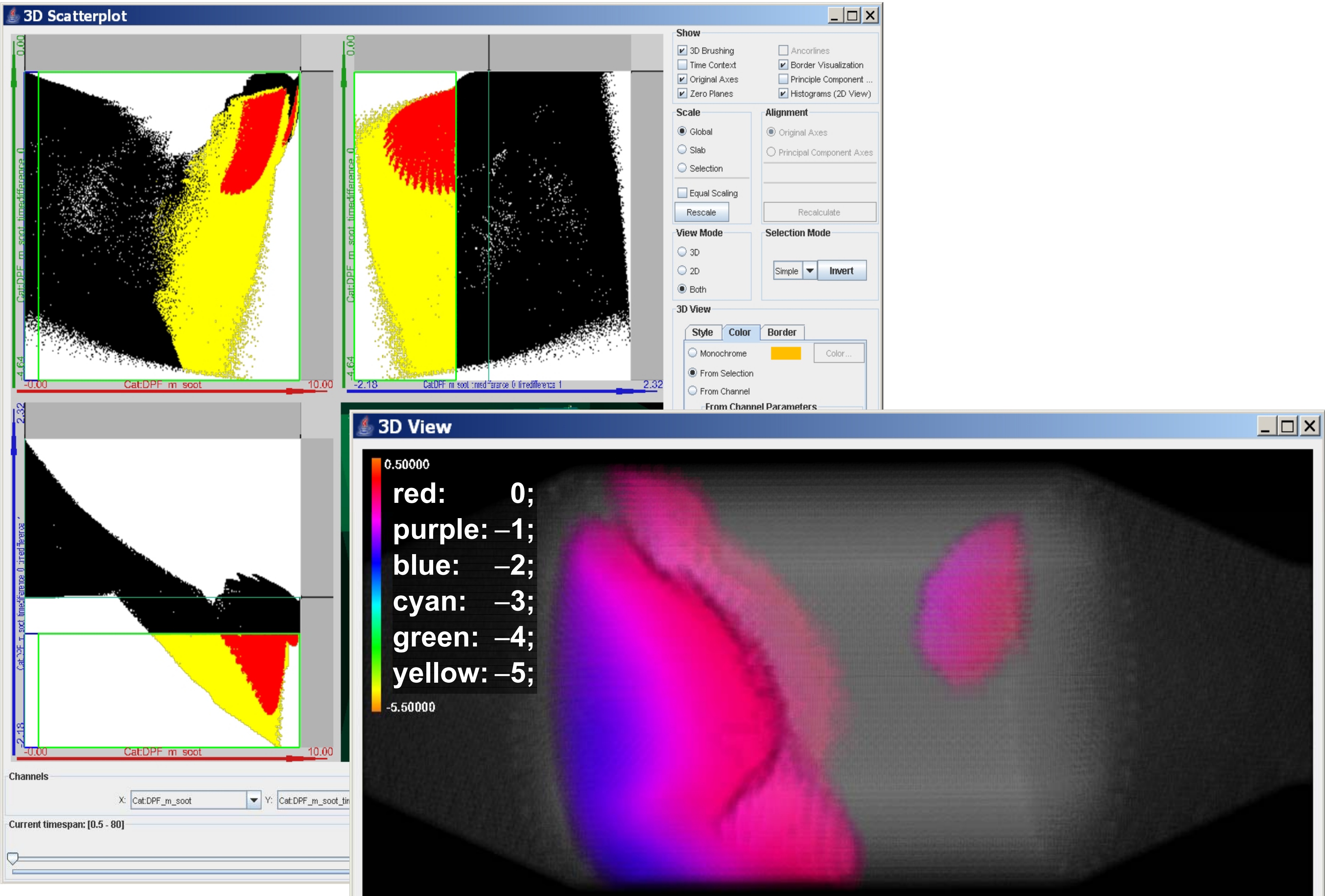

3D Scatterplot
Show
3D Brushing
Time Context
Original Axes
Zero Planes
Ancorlines
Border Visualization
Principle Component ...
Histograms (2D View)
Scale
Global
Slab
Selection
Equal Scaling
Rescale
Alignment
Original Axes
Principal Component Axes
Recalculate
View Mode
3D
2D
Both
Selection Mode
Simple
Invert
3D View
Style
Color
Border
Monochrome
Color...
From Selection
From Channel
From Channel Parameters
Source Channel
Time/Angle
Spatial Combination:
Average
Temporal Combination:
Average
Depth Cueing
Halos
Cat:DPF_m_soot
-0.00
10.00
-2.18
2.32
-4.64
0.00
Channels
X: Cat:DPF_m_soot
Y: Cat:DPF_m_soot_timediffere...
Z: Cat:DPF_m_soot_timediffere...
Current timespan: [0.5 - 80]
Lock Slab

t=15s

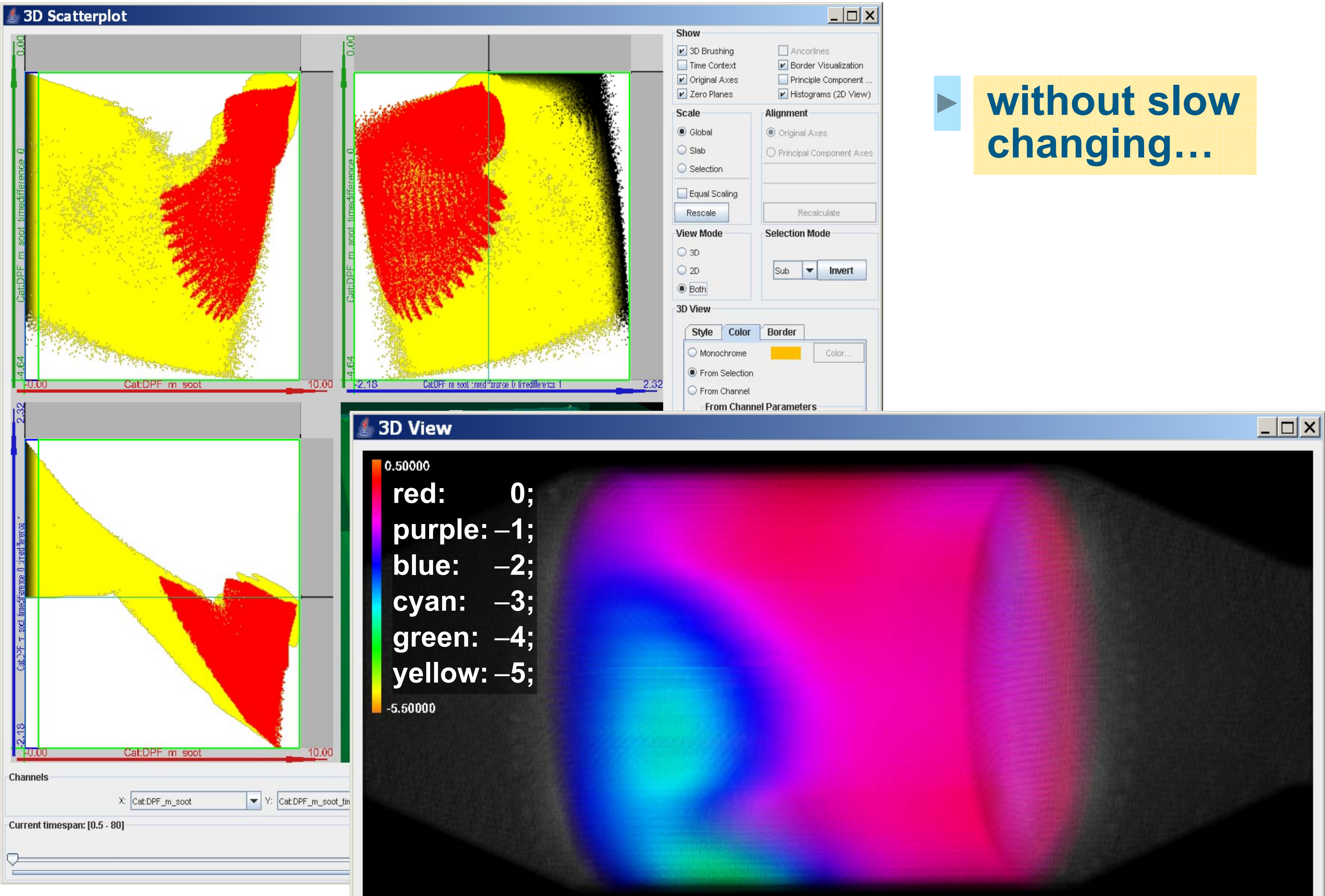


▶ **smallest Δ²soot only…**

t=15s, smallest Δ^2soot

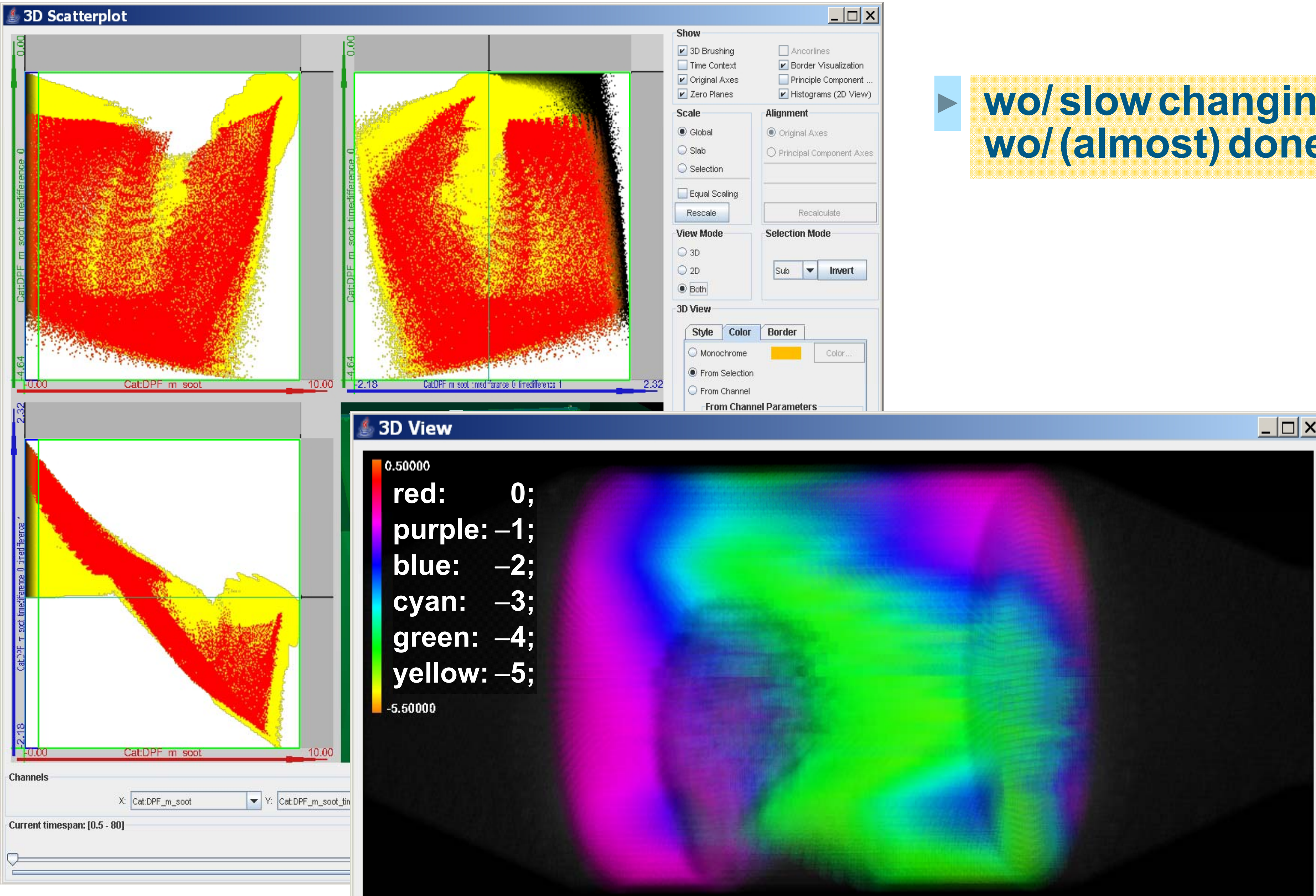


t=20s



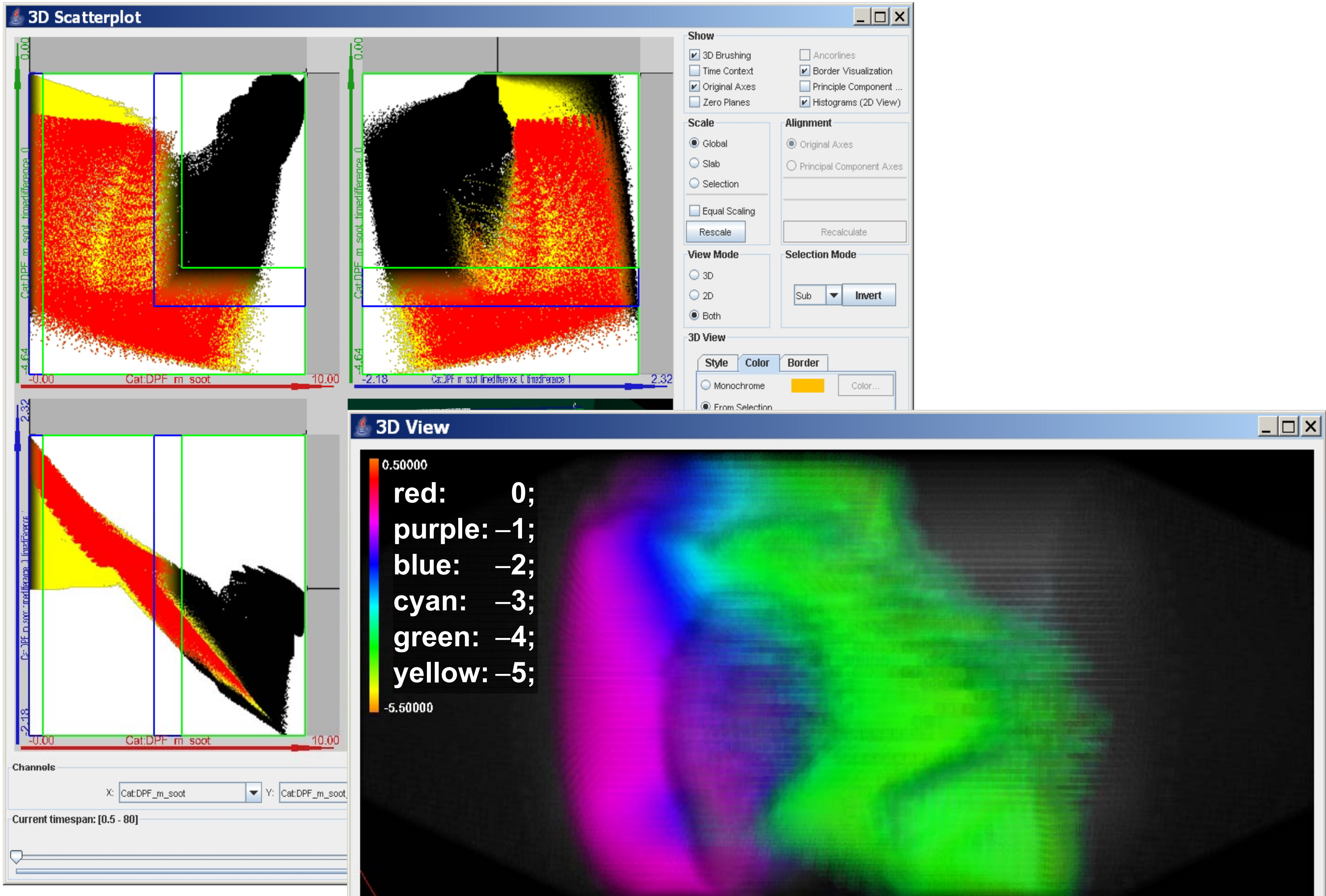
without slow changing…

t=30s

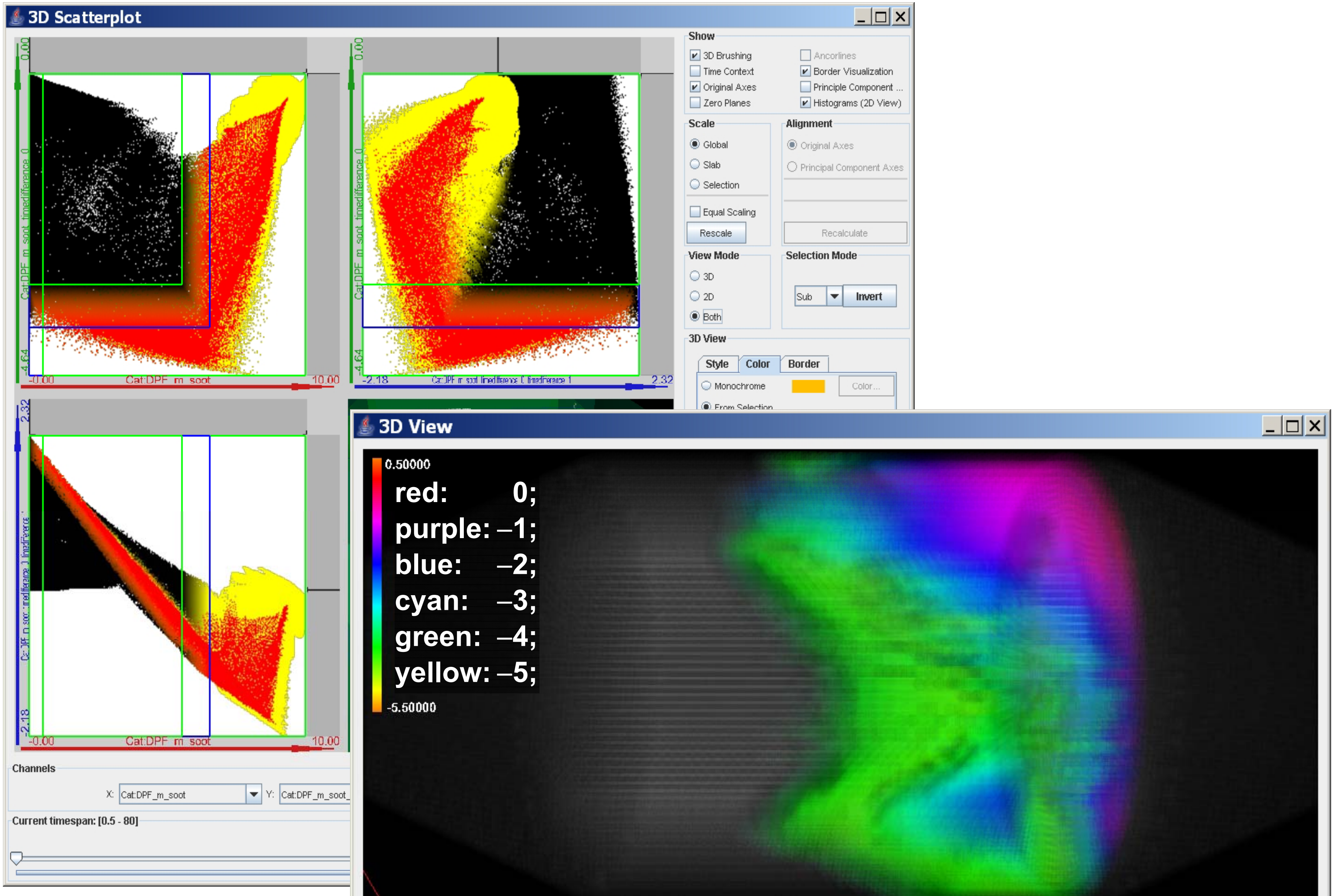


- wo/ slow changing,
  wo/ (almost) done..

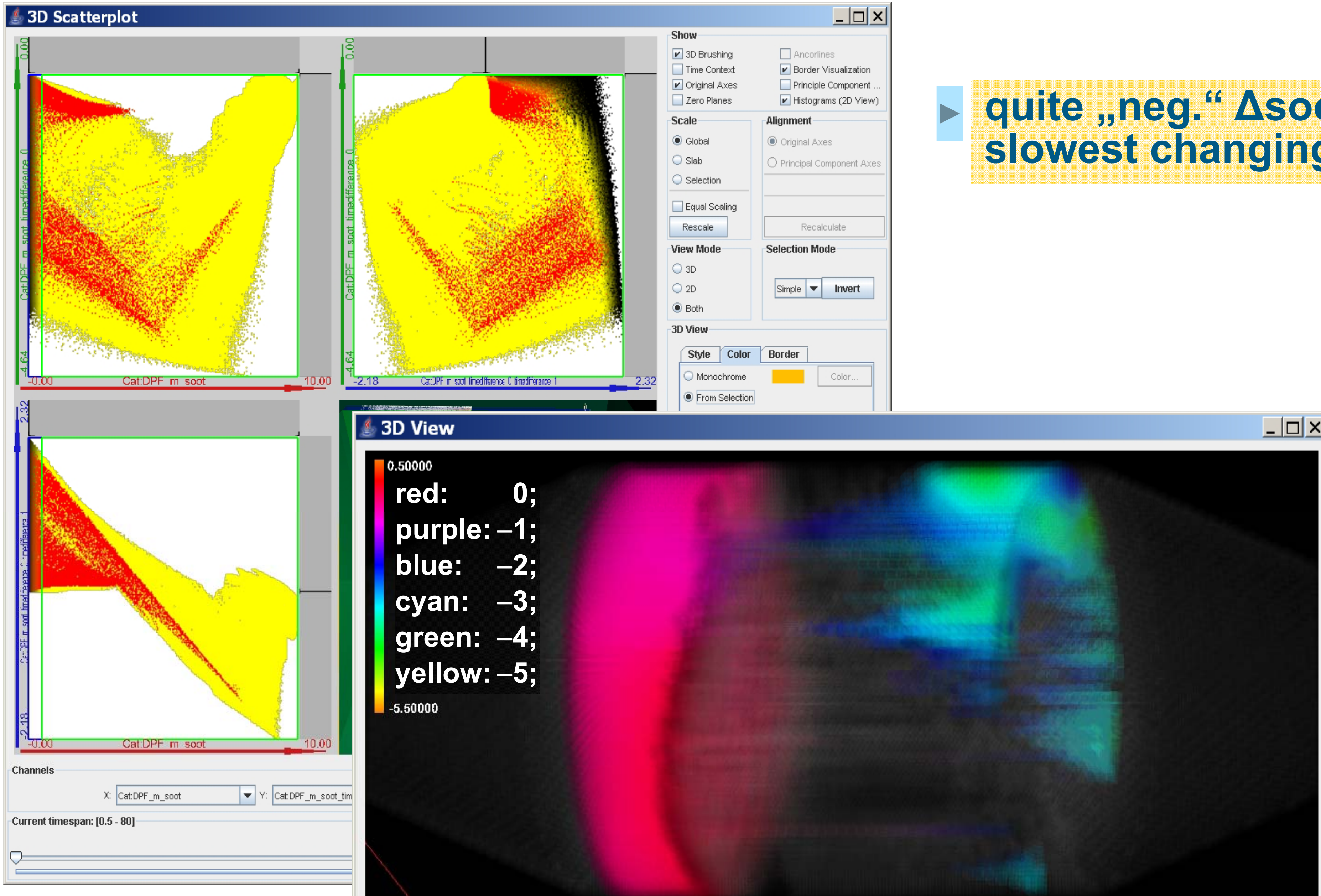
t=30s, without slow changing



t=30s, without (almost) done

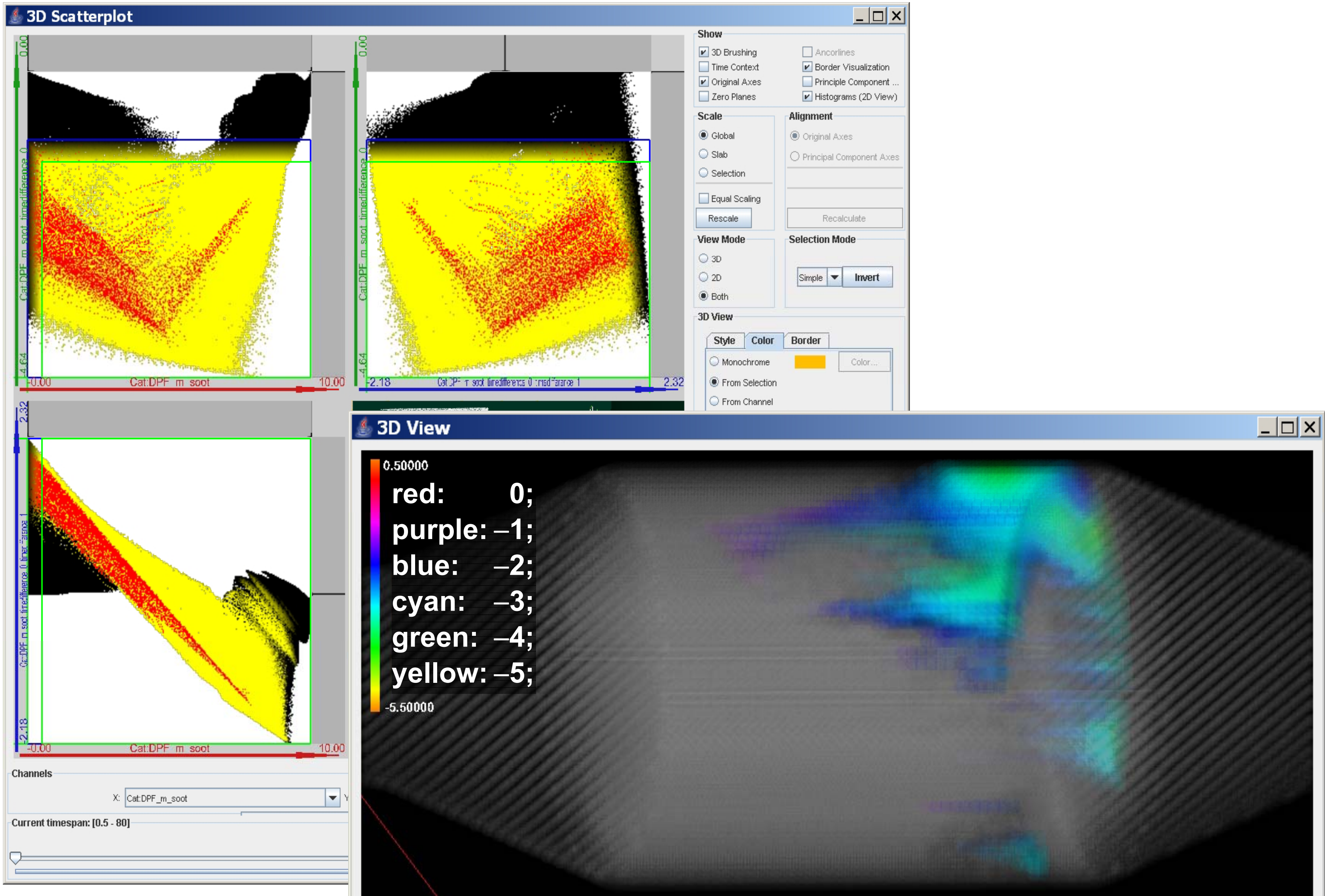


t=40s

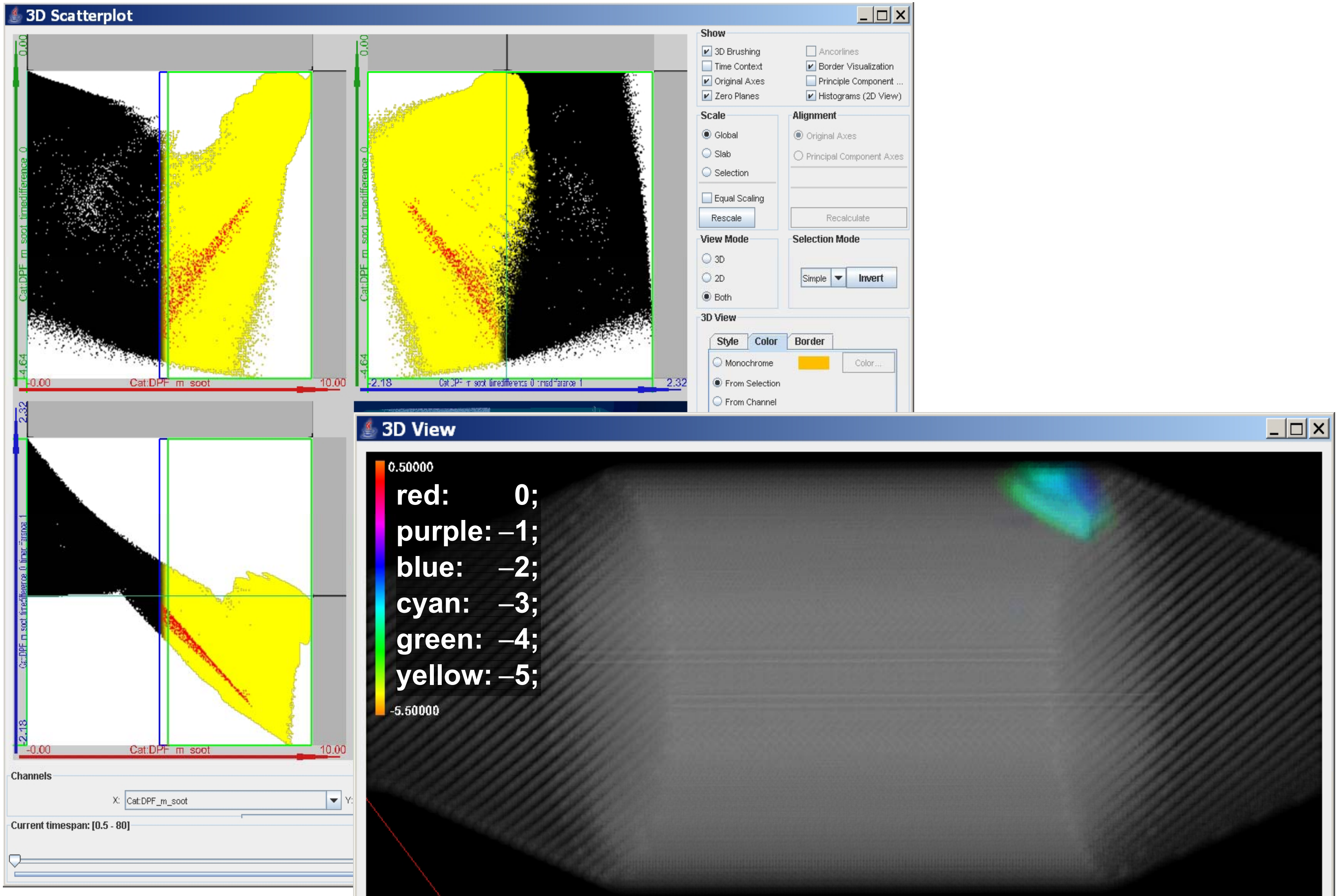


▶ quite „neg.“ Δsoot, slowest changing..

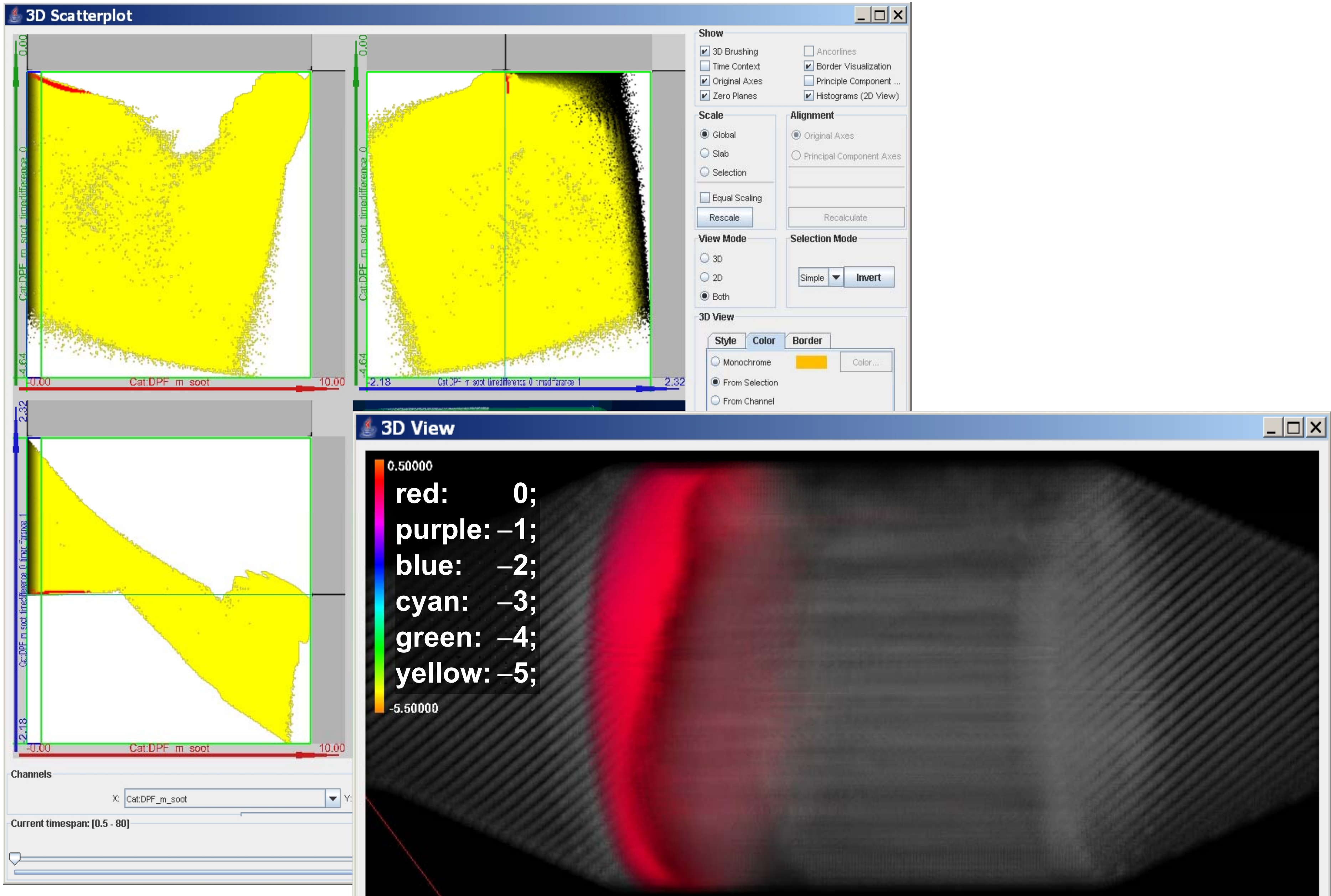
t=40s, “quite” negative Δsoot



t=40s, slowest changing

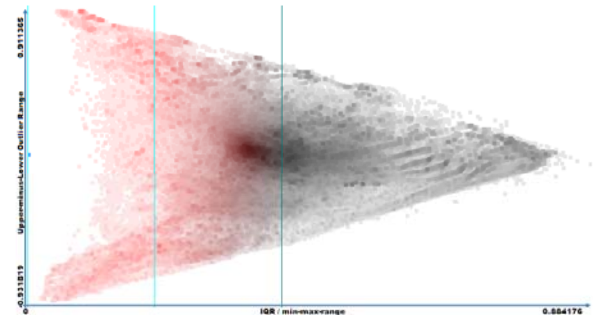


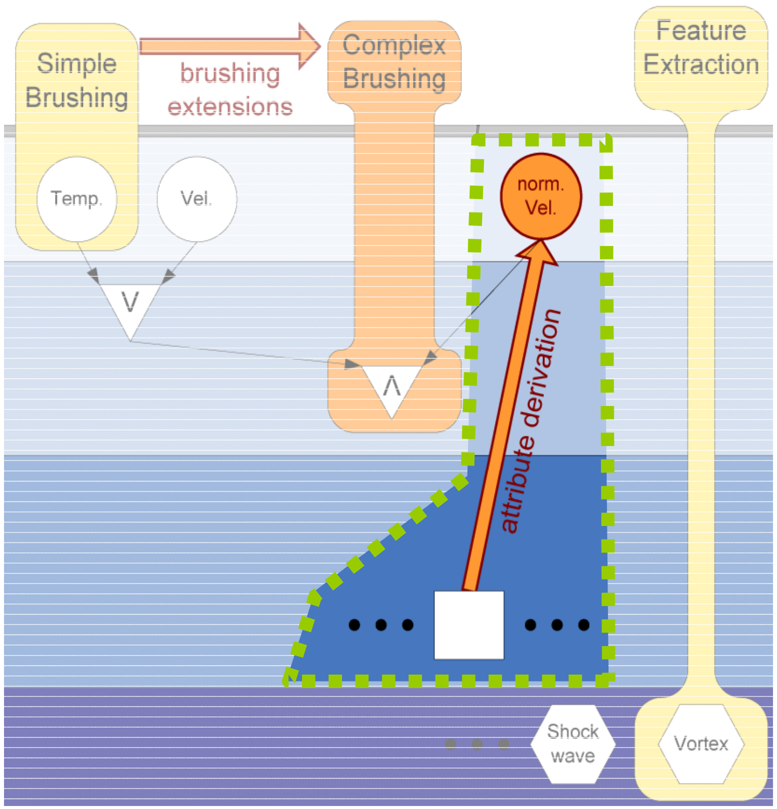
t=60s


3D Scatterplot
Show
3D Brushing
Time Context
Original Axes
Zero Planes
Ancorlines
Border Visualization
Principle Component ...
Histograms (2D View)
Scale
Global
Slab
Selection
Equal Scaling
Rescale
Alignment
Original Axes
Principal Component Axes
Recalculate
View Mode
3D
2D
Both
Selection Mode
Simple
Invert
3D View
Style
Color
Border
Monochrome
Color...
From Selection
From Channel
Cat:DPF_m_soot
0.00
10.00
2.32
-2.18
4.64
Channels
X:
Cat:DPF_m_soot
Current timespan: [0.5 - 80]
3D View
0.50000
red: 0;
purple: –1;
blue: –2;
cyan: –3;
green: –4;
yellow: –5;
-5.50000

IVA: Attribute Derivation

- Further interesting opportunities
  - re-projecting the data
    - f.i. according to PCA
    - data shear
  - statistical analysis
    - moments of data subsets
    - data in relation to moments, e.g., z-score
  - scale-space repr.
- Attribute derivation
  \+ advanced brushing
  = access to complex features



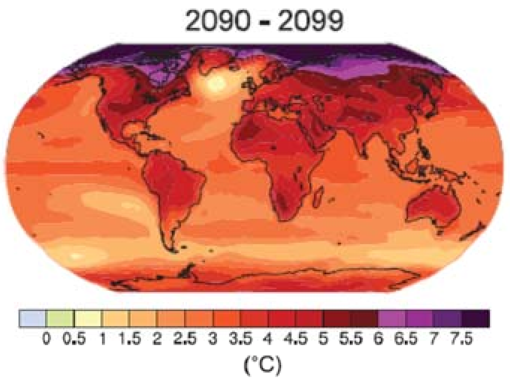


High-dimensional Scientific Data

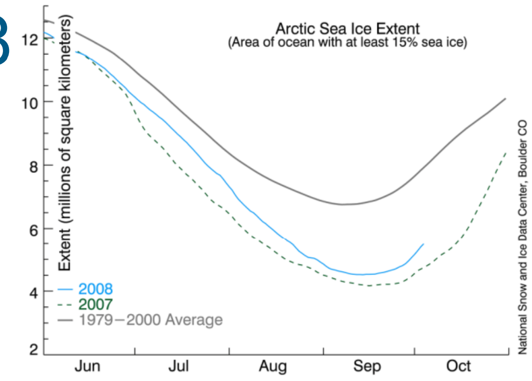
- Considering “scientific” data **f**(**x**), i.e.,
  - some measured / simulated / modeled data **f**,
    e.g., **f** being temperature, pressure, velocity, etc.,
  - wrt. some domain **x**,
    with **x** being 2D or 3D space, time, parameters, etc.
- If **x** is high-dimensional (>3),
  then “low-level” IVA is hard
  - example: 100 runs of time-dependent 3D sim. data
  - reducing the dimensionality can help
- Means to reduce the dimensionality
  - selection, e.g., through sampling
  - aggregation, e.g., by averaging
  - etc.

Integrating Statistics **and** IVA

[from IPCC AR #4, 2007]



- Statistics allow to assess distributional characteristics of sets of data,
  e.g., along one data dimension
- Examples:
  - map showing the average temperature in ten years
  - accumulated sea ice in summer 2008

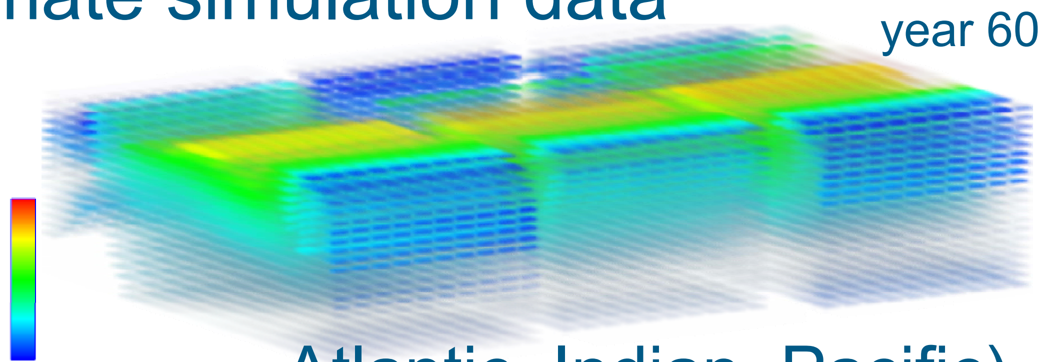


- Statistics can be reintegrated into IVA through attribute derivation
  - mean, variance
  - median, 1st & 3rd quartile, IQR
  - min, max, min–max range
  - etc.

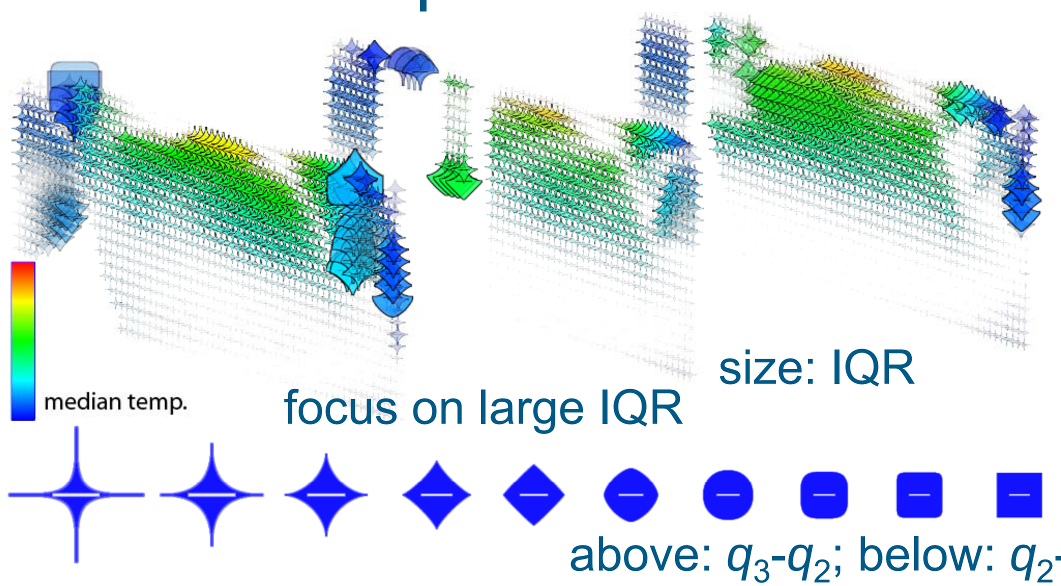
Brushing “Boxplots”

[J. Kehrer et al., submitted]

- Example: multi-run climate simulation data
  - 10•10=100 runs of time-dependent (250 time steps) ocean simulation (3 2D sections: Atlantic, Indian, Pacific)



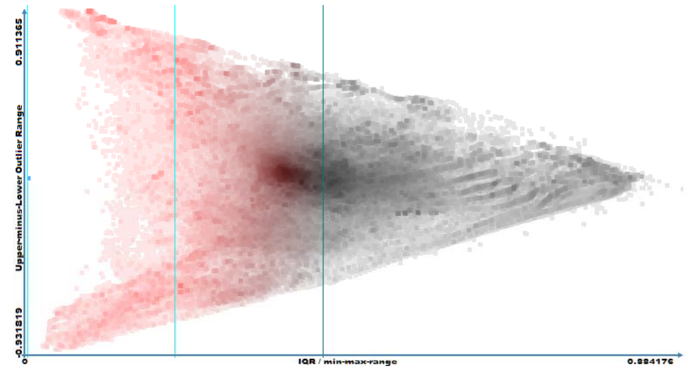
- Considering statistics wrt. the multiple runs
  - derivation on demand
  - visualization, e.g., glyph-based (⇨)
  - basis for complex analysis (next slide)



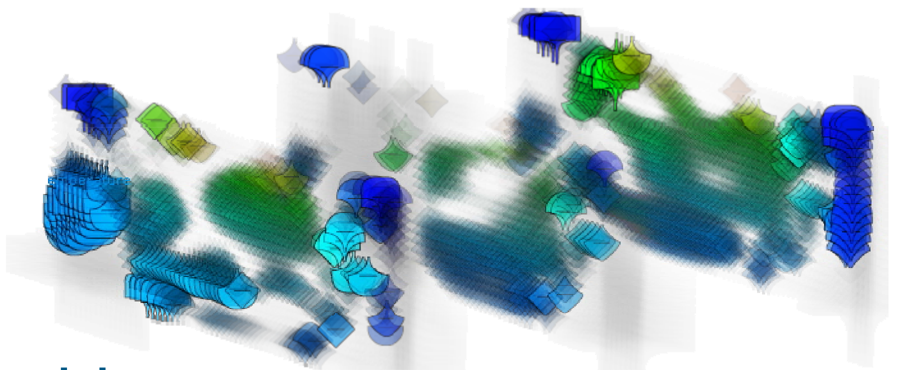
Brushing “Boxplots”

[J. Kehrer et al., submitted]

- Analyzing outliers
  - derivation of IQR / (max–min)
    - large, i.e., ≈1: no outliers
    - small, i.e., ≈0: some far outliers
  - derivation of upper/lower outlier range,
    UOR = $(\max - q_3) / (\max - \min)$,
    LOR = $(q_1 - \min) / (\max - \min)$,
    and ULR = UOR–LOR
    - positive, if max far away
    - negative, if min far away
  - scatterplot of both and brushing
- The according IVA loop
  - show, derive, show, brush, …
  - very powerful analysis approach



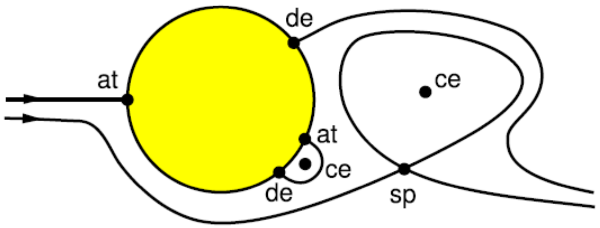
focus on small IQR

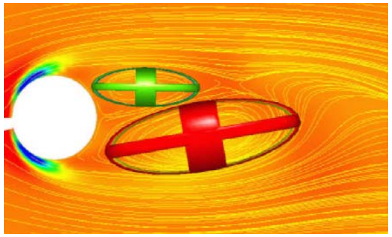


size: IQR (inverted)
above: UOR; below: LOR

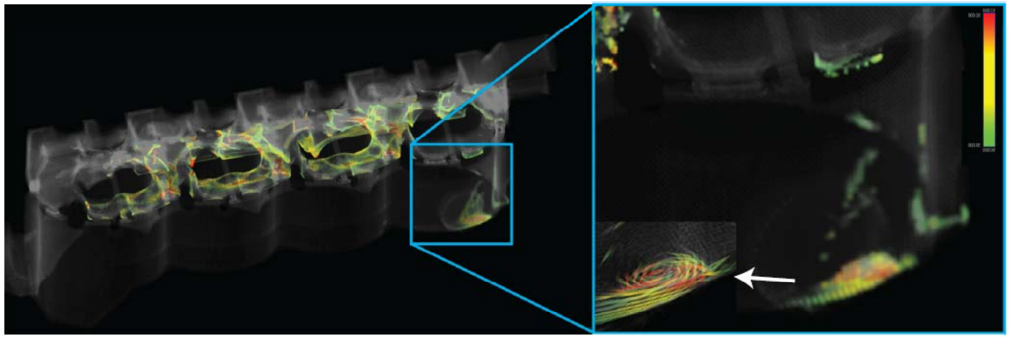
IVA **beyond** Complex Analysis (level 4)

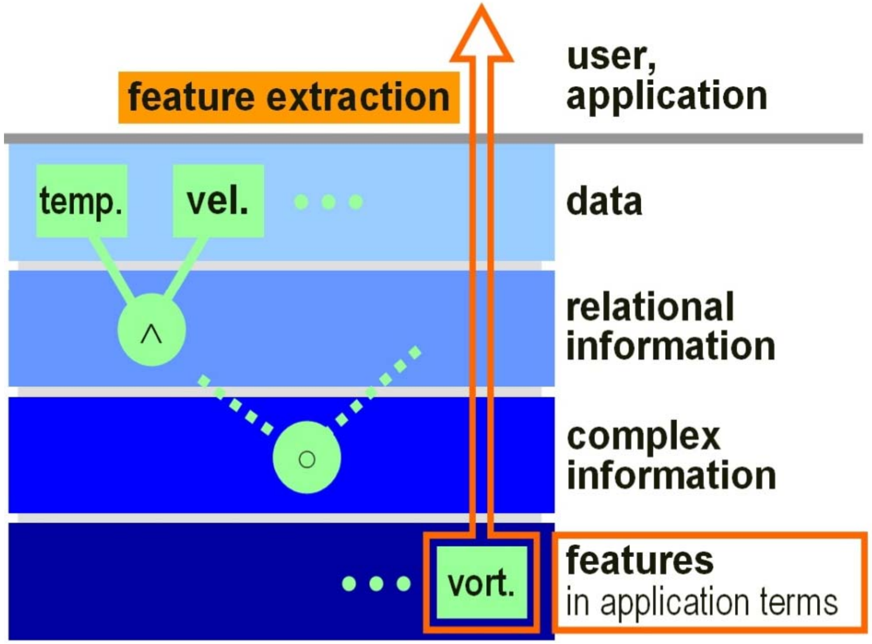
- **Of course there's more**:
  - approaches that "leave" the field
  - specialized feature extraction [Post et al., 2003]
  - etc.



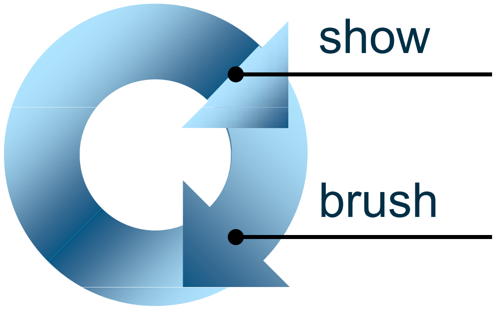


- A lot of good literature available
- Much can be embedded within IVA, also!
  - code as field [Bürger et al., '07]



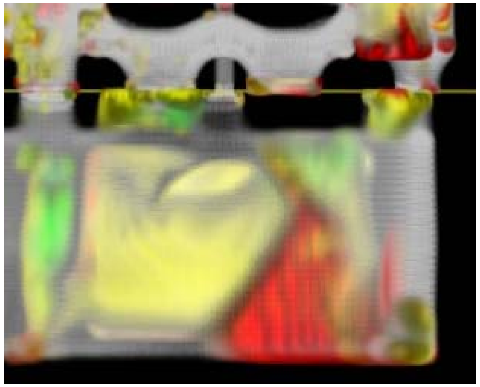


Discussion of IVA Levels (1)

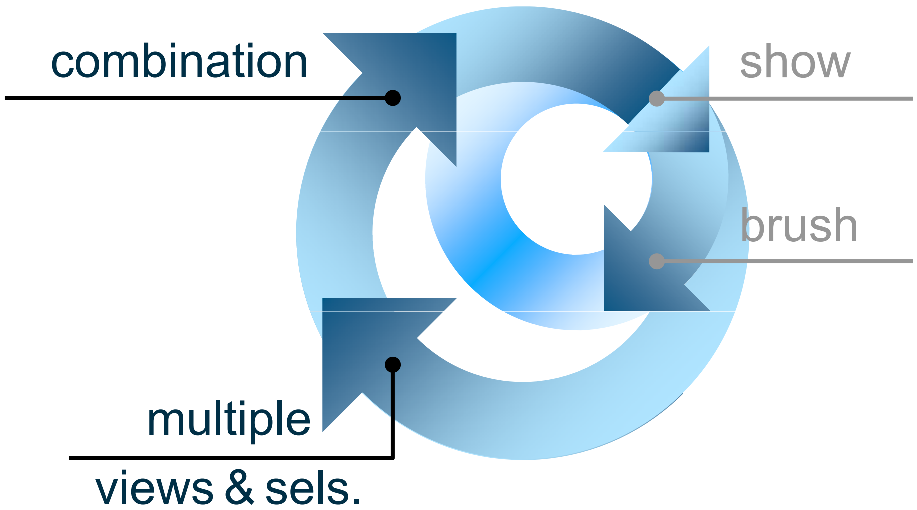


- **Show & brush**:
  - satisfies KISS principle
    - one brush
    - simple linking
    - conceptually simple
  - solves (maybe) 80% of all problems (Pareto rule)
  - implemented in many cases

Example:

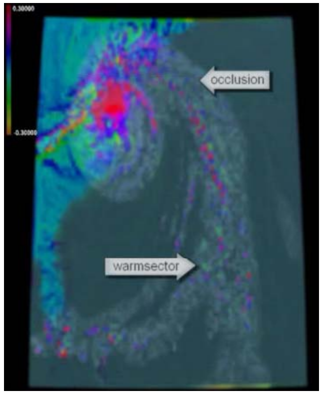


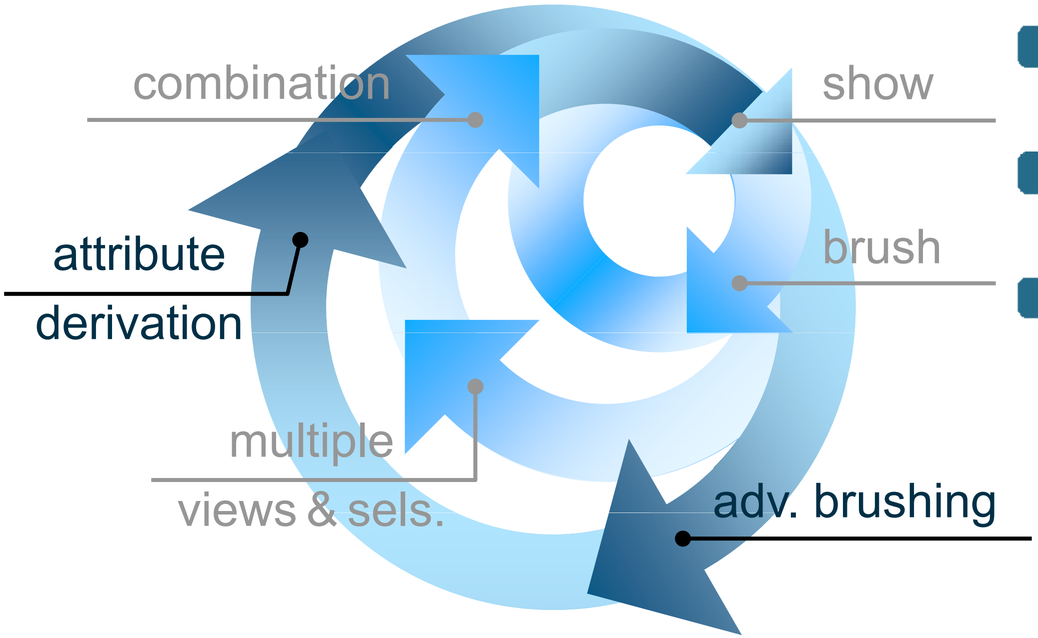
Discussion of IVA Levels (2)



- Show & brush
- **Relational analysis**:
  - coherent data / interaction metaphor space,
  - but allows for more complex queries
  - logical combinations match natural language

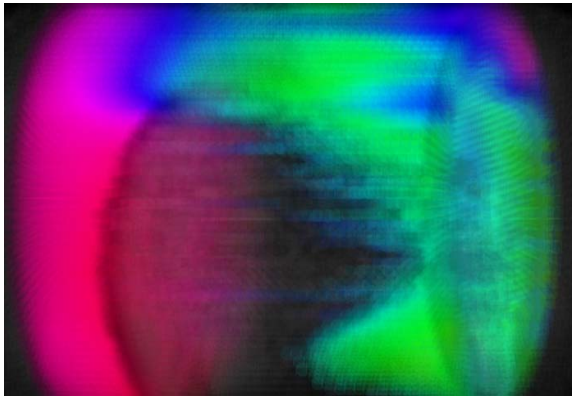
Example:



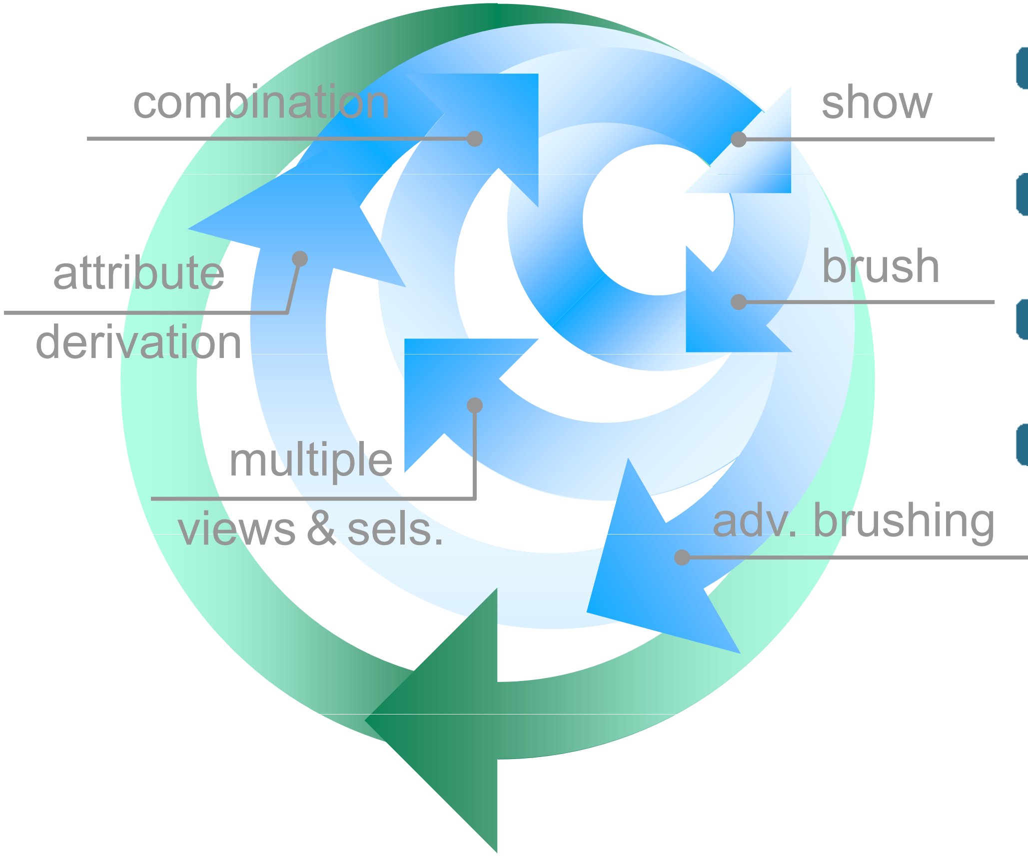


- Show & brush
- Relational analysis
- **Complex analysis**:
  - extends data / interaction metaphor space
    - additional data derivatives
    - additional brushing opportunities
  - combination of computational and interactive analysis very powerful!

Example(s):



Discussion of IVA Levels (4)



- Show & brush
- Relational analysis
- Complex analysis
- Approaches beyond…
  - "container" for approaches that go beyond DOI-based IVA

Really attractive to have all in one (IVA) framework!

Applications

- IVA of time-dep. 3D CFD data (engineering)
- IVA of industrial ensemble simulation data
- IVA of medical perfusion scans (3D+time)
- IVA of meteorological / climate research data
- IVA of sensor network data
- IVA of customer relation management (CRM) data
- …

Conclusions

- IVA useful in many application scenarios
  - follows common patterns (**x**⇨**d**, **d**⇨**x**, **d**⇨**d**)
- IVA enables a visual dialog with the data
  - from data to information / knowledge (and back)
- Iterative concept enables steered analysis
  - conquering the unexpected
    - both in terms of findings,
    - but also in terms of analysis approaches
  - facilitates reasoning, leads to additional learning, empowers the expert user (even makes experts!)
- IVA as useful exploratory research methodology
  - hypothesis generation
  - analysis prototyping

Acknowledgements

- You! Thank you for your attention! ;–)
- **Funding agencies, cooperating companies/…,**
  FFG, AVL List GmbH, EU(SemSeg, VisMaster), …
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- **The Meister**!

final plug:
we are hiring!

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